SUBCOURSE	EDITION
MM0455	7

POTENTIOMETRIC METERS

(DEVELOPMENT DATE: 31 MARCH 1987)

THE ARMY INSTITUTE FOR PROFESSIONAL DEVELOPMENT
ARMY CORRESPONDENCE COURSE PROGRAM

IPD
READINESS/ PROFESSIONALISM
THRU GROWTH

US ARMY CALIBRATION SPECIALIST
MOS 35H SKILL LEVELS 1, 2, 3, and 4 COURSE

POTENTIOMETRIC METERS

SUBCOURSE NO. SM0455-7
(Developmental Date: 31 March 1987)

US Army Signal Center and Fort Gordon
Fort Gordon, Georgia

Four Credit Hours

GENERAL

Potentiometric meters will be very important to you as a calibration specialist. This course is designed to teach the knowledge necessary to perform tasks related to the calibration, maintenance, and repair of potentiometric meters. Information is provided on several tasks which are performed in the Army Calibration Laboratory and the Army TMDE Support Team. The subcourse is presented in five lessons, each lesson corresponding to a terminal objective as indicated below.

Lesson 1: POTENTIOMETRIC METER PRINCIPLES

TASK: Describe and identify theory and terminology used in the application of potentiometric meters.

CONDITIONS: Given information and illustrations about theory and terminology relating to the application of potentiometric meters.

STANDARDS: Demonstrate competency of the task skills and knowledge by correctly responding to 75 percent of the multiple-choice test covering the theory and terminology of potentiometric meters.

Lesson 2: THE DC POTENTIOMETER SYSTEM

TASK: Describe the operation of the DC potentiometer system.

CONDITIONS: Given information and illustrations about use and operation of the DC potentiometer system.

STANDARDS: Demonstrate competency of the task skills and knowledge by correctly responding to 80 percent of the multiple-choice test covering the DC potentiometer system.

Lesson 3: PRECISION VOLTAGE MEASUREMENT OF THE STANDARD CELL

TASK: Describe and identify theory, terminology, and procedures for precision voltage measurement of the standard cell.

CONDITIONS: Given information and illustrations about theory, terminology, and procedures for precision voltage measurement of the standard cell.

STANDARDS: Demonstrate competency of the task skills and knowledge by correctly responding to 80 percent of the multiple-choice test covering precision voltage measurement of the standard cell.

Lesson 4: NULL DETECTOR 845AR

TASK: Describe and identify theory, operation, and troubleshooting of Null Detector 845AR.

CONDITIONS: Given information and illustrations about theory, terminology, operation, and troubleshooting of Null Detector 845AR.

STANDARDS: Demonstrate competency of the task skills and knowledge by correctly responding to 80 percent of the multiple-choice test covering Null Detector 845AR.

Lesson 5: DIFFERENTIAL VOLTMETER MODEL 887AB/AN

TASK: Describe and identify theory, terminology, and operation of Differential Voltmeter Model 887AB/AN.

CONDITIONS: Given information and illustrations about theory, terminology, and operation of Differential Voltmeter Model 887AB/AN.

STANDARDS: Demonstrate competency of the task skills and knowledge by correctly responding to 80 percent of the multiple-choice test covering Differential Voltmeter Model 887AB/AN.

(These objectives support the following SM tasks)

113-574-1007	Troubleshoot Null Detector 845AR
113-574-5021	Calibrate Differential Voltmeter 887AB/AN
113-574-5030	Calibrate Voltage Divider 80E-10AN
113-574-1029	Troubleshoot Differential Voltmeter 887AB/AN
113-574-5083	Calibrate Voltage Divider RV722
113-574-6029	Perform Surveillance on Standard Cells in Working and Reference Groups
113-574-5071	Calibrate DC Transfer Standard 730A/AB

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THE PROPONENCY FOR THIS SUBCOURSE HAS CHANGED FROM SIGNAL TO MISSILES AND MUNITIONS SCHOOL. WHENEVER REFERENCE IS MADE TO SM0455 WITHIN THIS SUBCOURSE, THE STUDENT SHOULD WRITE IN MM0455.

Whenever pronouns or other references denoting gender appear in this document, they are written to refer to either male or female unless otherwise indicated.

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INTRODUCTION TO POTENTIOMETRIC METERS

Potentiometric meters will be very important to you as a calibration specialist. Among the most accurate and reliable measuring devices you will encounter are the DC potentiometer system, the null detector, and the differential voltmeter. Although these instruments differ in operation, they are similar in that all use the same method of measurement.

The purpose of this subcourse is to provide the calibration specialist with an overall view of the development, use, and operation of potentiometric meters, and to provide some guidelines on how to troubleshoot potentiometric meters. Information is also provided on the US Army Volt Program and its application to the US Army Test, Measurement, and Diagnostic Equipment support mission.

LESSON 1
POTENTIOMETRIC METER PRINCIPLES

TASK

Describe and identify theory and terminology used in the application of potentiometric meters.

CONDITIONS

Given information and illustrations about theory and terminology relating to the application of potentiometric meters.

STANDARDS

Demonstrate competency of the task skills and knowledge by correctly responding to 75 percent of the multiple-choice test covering theory and terminology of potentiometric meters.

REFERENCES

None

Learning Event 1:
DESCRIBE THE POTENTIOMETER AND ITS APPLICATION

1. The laboratory potentiometer described here is a precision-measuring instrument; it is not an electrical component and should not be confused with the three-terminal variable resistor, which is also referred to as a potentiometer. It acts to compare directly and accurately, through null output indication, unknown DC voltages with reference-derived voltages. It is unlike the instrument bridge, which (by nulling techniques) makes accurate comparisons of impedances, one of which is the standard or reference component. Similar to bridge instruments, most potentiometers are designed for precision laboratory use and most often obtain comparisons by manual operation.

2. For reference and standardization, the potentiometer requires the stable precise voltage delivered by a standard cell or zener diode voltage source plus the ratios obtained from precisely and accurately calibrated, fixed and variable resistors. The bridge, on the other hand, derives its accuracy from reference to an accurate resistance standard.

3. The potentiometer is limited in basic voltage range by the standard cell, so it must be used with resistance ratio devices for extension to other voltage ranges. Its chief advantage lies in direct applicability to voltage-related devices in the measurement of current and resistance.

Learning Event 2:
DESCRIBE POTENTIOMETER DEVELOPMENT

1. Early methods in standardization and calibration of dc instruments stemming from standard cell-referenced potential difference, developed across a resistor, were resolved in the Poggendorf method shown schematically in Figure 1-1.

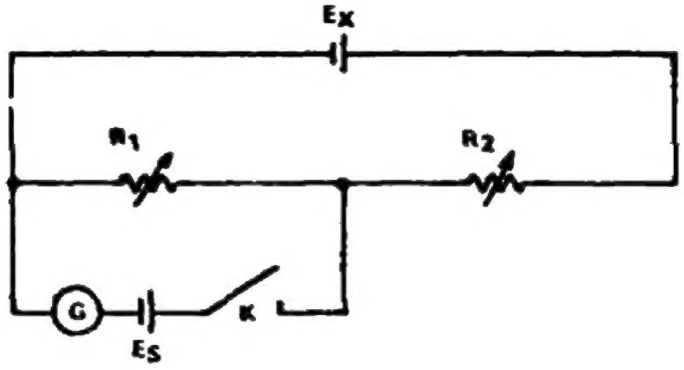


Figure 1-1. Poggendorf voltage comparison method

2. The battery voltage E_X is to be determined from the accurately known voltage of the standard cell E_S and the standard resistors R_1 and R_2. Referring to Figure 1-1, the assumption is made that $R_1 + R_2$ is sufficiently high so that very little current flows through E_X and its internal fall of potential due to internal resistance times the current is zero. It is assumed, further, that the full voltage E_X is the actual potential difference developed across $R_1 + R_2$.

a. Hence, with the key (K) open, the current I in either R_1 or R_2 is

$$I = \frac{E_x}{R_1 \quad R_2}$$

and the potential difference PD_1 across R_1 is

$$PD_1 = \frac{E_x \quad R_1}{R_1 + R_2}$$

b. The standard cell E_S is connected through a galvanometer (G), so that, when the key is operated, the EMF of the cell will be in opposition to PD_1. For balance, R_1 and R_2 are varied, keeping their sum constant, until

PD_1 is made equal to E_S, as indicated by zero deflection of the galvanometer when the key is operated. Under this condition,

$$E_s = \frac{E_x}{R_1 + R_2} R_1$$

Thus:

$$E_x = E_s \frac{R_1 + R_2}{R_1}$$

Learning Event 3:
DESCRIBE THE SLIDE WIRE POTENTIOMETER

1. To avoid the assumption of the earlier Poggendorf circuit of Figure 1-1, in which the current through E_X was considered to be essentially zero, the modern "slide wire" type potentiometer was devised. In this type, an auxiliary or "working battery" has been added to maintain a constant current through its associated calibrated resistance. Its basic circuit is shown in Figure 1-2.

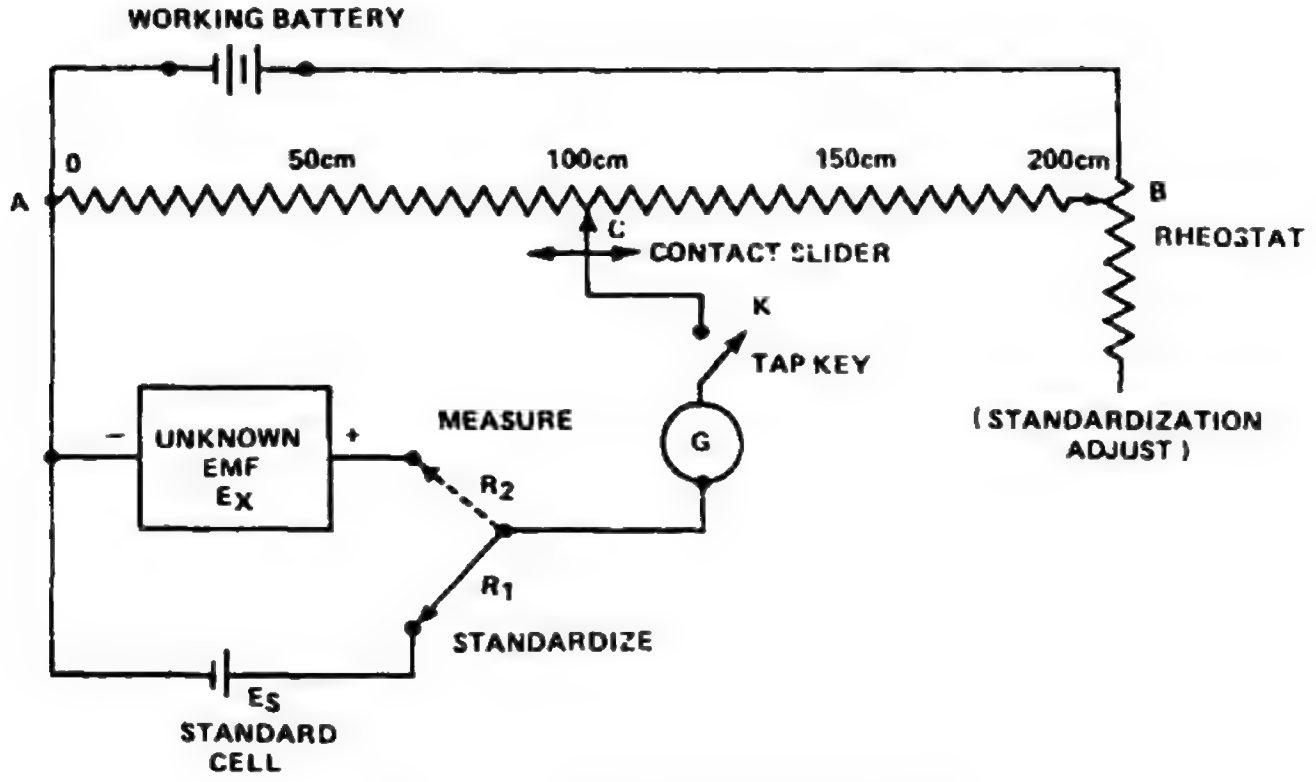


Figure 1-2. Slidewire potentiometer

2. The basic voltage comparisons can thus be made by first establishing an accurately known voltage drop across a portion of the calibrated resistance with a standard cell and then determining the unknown voltage by the ratio of the calibrated resistances.

3. Referring to Figure 1-2, the calibrated resistance is represented by the wire, (AB), shown with a scale along its length. This wire has uniform resistance per unit of length and is equipped with a contacting slider, (C). In operation, the rheostat is first adjusted to provide a constant current in (AB) from the working battery. With the standard cell E_S switched into the circuit, let r be the resistance from (A) to (C) when the key is closed and the galvanometer deflection is zero. Let r_2 be the resistance to the slider with the unknown EMF E_X in the circuit, the galvanometer deflection at zero and the current in (AB) the same as before. For these conditions, the current in the slide wire will be:

$$I_{AB} = \frac{E_s}{r_1} = \frac{E_x}{r_2}$$

and the unknown EMF E_x will be:

$$E_x = E_s \frac{r_2}{r_1}$$

4. The potentiometer can be made direct-reading by dividing the slide wire into, say, 200 divisions and adjusting the rheostat for 2.00 volts across (AB). This can be done by the use of the standard cell. If the cell has an EMF of 1.018 volts, the slider can be set at 101.8 divisions (cm) from the scale zero (at point A) and the rheostat adjusted to obtain zero galvanometer deflection when (K) is closed. Now position 101.8 cm on the slider scale represents 1.018 volts, and the value of any unknown EMF within the range of the instrument can be read at balance directly from the scale by multiplying the scale reading by .01. For example, 151.8 cm times .01 equals 1.518 volts.

5. Commercial potentiometers incorporate slide wire arrangements which are usually in the form of single or multiturn rotating drums that afford a long length of slide wire. To allow for greater accuracy of readout without the necessity for an unduly long slide wire, the drum resistor is usually in series with a multistep resistor, which can readily be set with a rotary dial. The precision potentiometer, (fig 1-3), incorporates these features in a single-range device that enables accurate readings to be made from 0 to 1.6 volts.

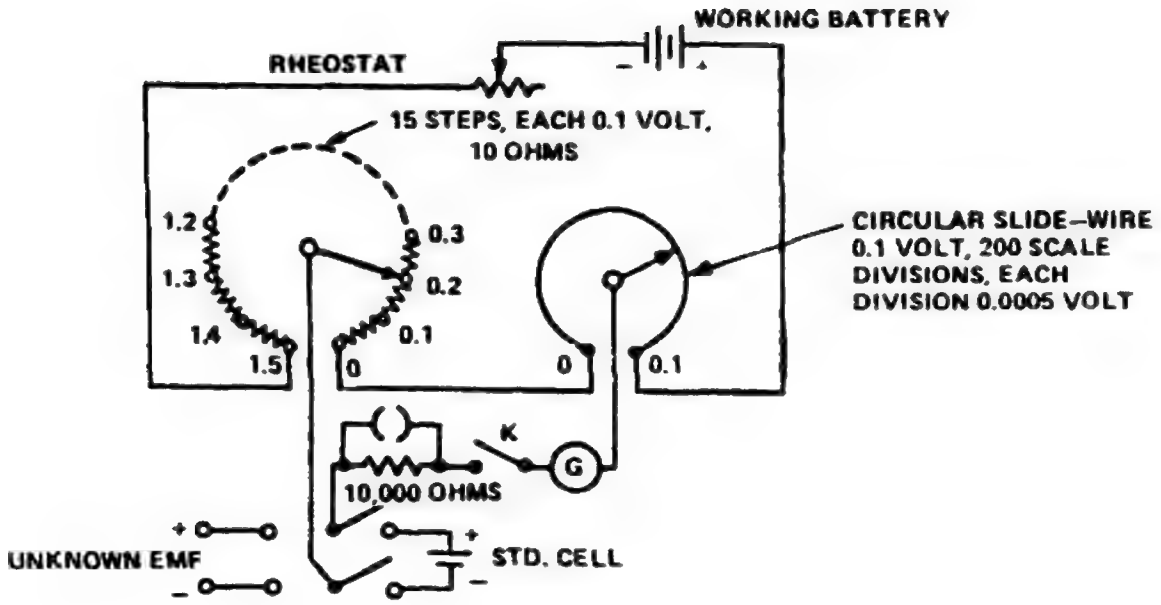


Figure 1-3. Slide wire potentiometer

Learning Event 4:
DESCRIBE THE TWO-RANGE POTENTIOMETER

1. A simplified circuit of a two-range potentiometer is shown in Figure 1-4. Selection of either the 1.6 or .16-volt range is provided by switch S_1. As in the single-range instrument, the rheostat adjusts the working battery circuit to the proper voltage. The standard cell E_S and the unknown EMF E_X are connected by means of switch S_3. The galvanometer (G) is shown with its protective resistance R_p and shunting switch S_2. For the high range, the dials may be read directly; for the low range, the dial readings are multiplied by the factor .1.

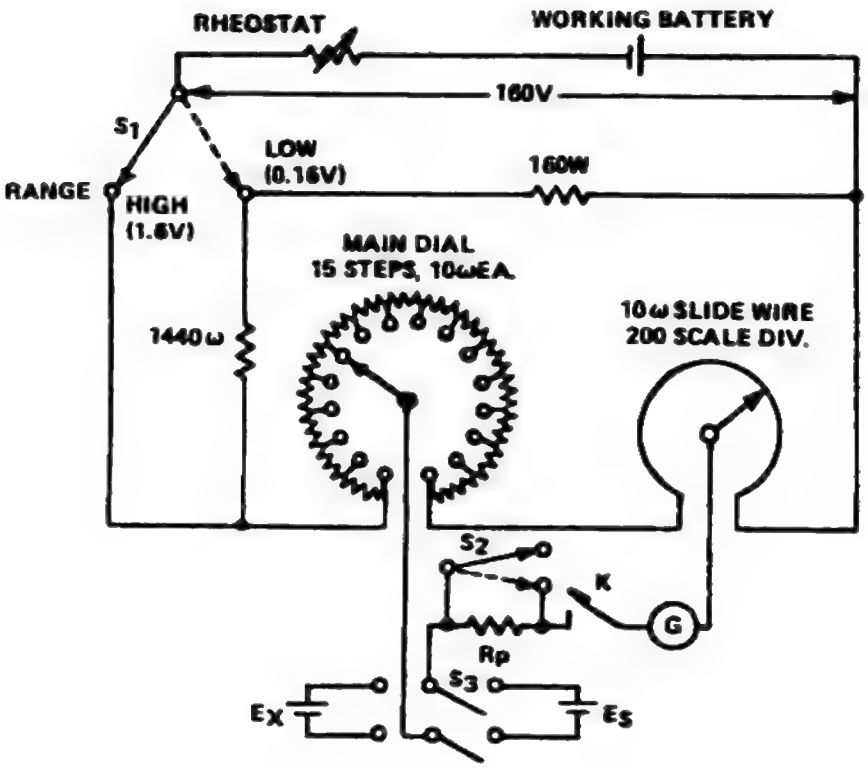


Figure 1-4. Two-range potentiometer

2. It should be particularly noted that, in the potentiometer method of measurement of an EMF, there is no current being drawn from this EMF when balance is reached. Thus, the measurement of a source of voltage is completely independent of its internal resistance. Also of particular significance is the fact that the potentiometer operates on a ratio principle. The EMF to be measured is determined from the known standard cell voltage by the ratio of the resistances which are established to achieve the two conditions of balance. Therefore, the accuracy of the potentiometer is more dependent upon the correct relationship of the resistors used than the actual values of resistance employed.

Learning Event 5:
DESCRIBE THE VOLT BOX

1. For measurement of voltages above the upper potentiometer voltage limit, it is customary to use another ratio device called a "volt box" or voltage divider, (fig 1-5).

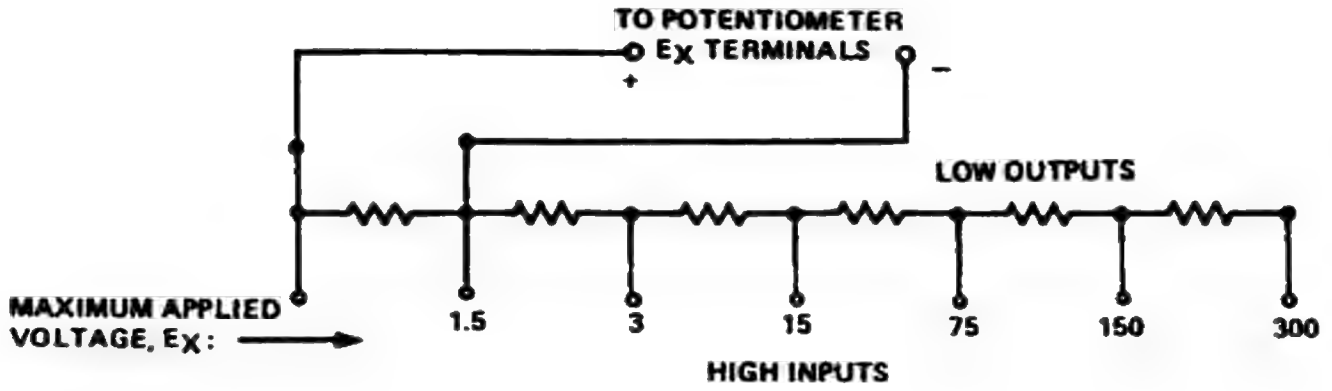


Figure 1-5. Volt box

2. The volt box is a series string of resistors with the tie points connected to binding posts. Range selection is accomplished by applying the voltage to be measured to the appropriate binding post or by a switch connected to the tie points. The voltage to be measured is applied across the series resistors and a lower voltage, tapped from one of the tie points, is measured by the potentiometer.

3. The voltage to be measured is applied to one of the connections that is equal to or greater than its value. The output applied to the potentiometer is taken from a binding post that is within its measuring range. Although this system is sufficiently accurate for most applications, it should be noted that the voltage divider consumes power from the source even when the potentiometer is at null, and therefore may produce lower readings due to the loading effect. This effect can be reduced by using high ohmic value resistors to make up the series of the volt box.

4. To employ the standard potentiometric measuring technique, we must first obtain a multiplication factor. To obtain the multiplication factor of the individual input binding posts, you simply divide the maximum EMF of the high binding post in use by the maximum of the low binding post in use. Or stated as a formula:

$$\text{multiplication factor} = \frac{\text{EMF max}}{\text{EMF min}}$$

a. We also use the multiplication factor to determine the approximate voltage present at the low EMF terminal when a voltage other than the maximum is applied to the input binding posts. To make this determination, divide the applied voltage by the multiplication factor, or simply:

$$\text{approximate output} = \frac{\text{applied voltage}}{\text{multiplication factor}}$$

b. To use the multiplication factor to determine the actual input voltage, first assume that 60 volts are applied to the .75-volt binding post and the potentiometer is monitoring the 1.5-volt terminal. As mentioned above, the multiplication factor must be determined. To do this, 75 is divided by 1.5 and a multiplication factor of 50 is obtained. Next, the approximate input voltage (60 volts) is divided by the multiplication factor (50). This gives 1.20 volts which will be preset on the potentiometer. The measured voltage is then multiplied by the factor of 50 to determine the EMF present at the 75-volt terminal, or,

input to volt box = multiplication factor x measured EMF

Learning Event 6:
DESCRIBE CARE AND PRECAUTIONS WHEN USING THE POTENTIOMETER

1. The first trials for balance should check the action of the protective resistance in both the galvanometer and the standard cell circuits to prevent injury from excessive currents.

a. Care must be exercised to minimize the current passing through the standard cell, since it is essentially an open-circuit device and its EMF is altered by polarization resulting from current flow.

b. The key should be depressed only momentarily to note the direction of needle movement; it should never be left closed.

c. The maximum cell current should be limited to a value below 10 microamperes, preferably to a fraction of a microampere.

2. To avoid short-circuiting the standard cell, it is best to connect it to the potentiometer carefully after all other connections have been made and to disconnect it first on dismantling the hookup. Careful checks should also be made of the polarity when connecting the standard cell and the working cell to the potentiometer. It may further be necessary to maintain the standard cell at a constant temperature and to check its EMF periodically.

3. False deflection of the galvanometer during damp weather measurements may require guard circuitry, for example, mounting the potentiometer equipment on insulating blocks, each of which rests on a metal electrode, and connecting the electrodes to the positive of the working battery or the highest external potential to which the potentiometer is connected.

a. Additional guard circuits may be necessary, if not included in the potentiometer, for prevention of stray currents at the detector binding posts, the galvonometer key, and the external voltage connections.

b. The galvanometer circuit should be protected by a high series resistance.

c. Electrostatic effects are usually minimized by the metal envelope which forms the potentiometer case.

4. Special-type cables are used when making potentiometric measurements. They are made of solid, untinned, shielded, twisted pair copper wire which is used to prevent electromagnetic pickup from external sources and also to prevent the thermocouple effect from being introduced by dissimilar metal contact. The possible introduction of thermal EMF is the reason for using untinned leads as interconnecting cables. All connections should be tightly made to reduce contact resistance and prevent intermittent operation. In making connections, always remember to observe polarity and never apply the high side of the potential to the low or common binding post. If this error is made, the potentiometer will be at the same potential above ground as the applied voltage, thus presenting a definite shock hazard.

Lesson 1
PRACTICE EXERCISE

1. For reference and standardization, the potentiometer requires

   a. A standard cell or zener diode voltage source
   b. Ratios obtained from fixed and variable precision resistors
   c. Neither a or b
   d. Both a and b

2. The chief advantage of the potentiometer in the measurement of current and resistance is its

   a. Direct applicability to impedance-related devices
   b. Direct applicability to capacitance-related devices
   c. Direct applicability to voltage-related devices
   d. Direct applicability to resistance-related devices

3. The early methods in standardization and calibration of dc instruments using a standard cell-referenced potential difference, developed across a resistor is known as

   a. The standard method
   b. The Poggendorf method
   c. The Tesla method
   d. The Edison method

4. Refer to Figure 1-1. If E_S is equal 1.018 volts, R_1 is adjusted for 8.0 and R_2 is adjusted for 1.3 what is the value of E_X ?

   a. 1.1667 volts
   b. 0.11667 volts
   c. 11.667 volts
   d. 116.67 volts

5. What device is added to the slide wire potentiometer to maintain a constant current through its calibrated resistance?

   a. Standard cell
   b. Current shunt
   c. Working battery
   d. Rheostat

6. Refer to Figure 1-2. What component is adjusted first to provide a constant current in R_1?

   a. Contact slider
   b. Rheostat
   c. Galvanometers
   d. Standard cell

7. Refer to Figure 1-2. If the rheostat is adjusted for 2.00 volts across AB, what is the value of the unknown EMF if the slider is set at 125.2?

   a. 1.252 volts
   b. 0.1252 volts
   c. 1.018 volts
   d. 12.52 volts

8. Refer to Figure 1-4. Which switch is used to select either the 1.6 or .16 volt range?

   a. K
   b. S2
   c. S1
   d. S3

9. How are measurements read on the low range of the two range potentiometer?

   a. Dial readings are multiplied by a factor of .01
   b. Dial readings are read directly
   c. Dial readings are multiplied by a factor of 10
   d. Dial readings are multiplied by a factor of .1

10. The accuracy of the potentiometer is dependent upon what relationship?

   a. The correct relationship of the resistors used
   b. The correct relationship of the actual values of resistance employed
   c. The correct relationship of the standard cell to the unknown EMF
   d. The correct relationship of the unknown voltage to the standard cell current

11. If the potentiometer reading is 1.3 volts and the volt box tap being used has a multiplication factor of 10, what is the applied voltage to the volt box?

   a. .13 volts
   b. 13 volts
   c. 130 volts
   d. 3 volts

12. How is the loading effect of the volt box reduced?

   a. By using high ohmic value internal resistors
   b. By using coupling capacitors
   c. By using low ohmic value internal resistors
   d. By using current shunts

13. Which current should be protected by a high series resistance?

    a. Galvanometer
    b. The potentiometer
    c. Standard cell
    d. Volt box

14. Why are the interconnecting cables shielded?

    a. Prevent inter cable capacitance
    b. Prevent electro-magnetic pickup
    c. Prevent thermal currents
    d. All the above

15. What will be the result if the low side of the source EMF is connected to the high side of the volt box?

    a. Nothing will result
    b. The standard cell will be short circuited
    c. A shock hazard will be present
    d. The output of the volt box will be double the source EMF

LESSON 2
THE DC POTENTIOMETER SYSTEM

TASK

Describe the operation of the dc potentiometer system.

CONDITIONS

Given information and illustrations about the use and operation of the dc potentiometer system.

STANDARDS

Demonstrate competency of the task skills and knowledge by correctly responding to 80 percent of the multiple-choice test covering the dc potentiometer system.

REFERENCES

Guildline Instruments technical manuals.

INTRODUCTION

In the Army Calibration Laboratory, the dc potentiometer system is the most accurate voltage measuring device. The system is comprised of a Model 9931 DC Comparator Potentiometer, a Model 9771 Constant Current Source (CCS), a Model 9460A Nanovolt Amplifier, a Model 9461B Galvanometer, and a Model 9154B Standard Cell Enclosure.

Learning Event 1:
DESCRIBE THE MODEL 9931 DC COMPARATOR POTENTIOMETER

1. Functional description. The Guildline Instruments Direct Current Comparator Potentiometer, Model 9931, is a seven-dial potentiometer which is used in conjunction with a CCS, a nanovolt amplifier, a standard cell enclosure, and a galvonometer to make precision voltage measurements (fig 2-1).

a. The instrument is designed to measure voltage in two ranges; 0 to 2 volts at an accuracy of ± (0.5 ppm of reading + 0.05 μV), and 0 to 0.2 volts at an accuracy of ± (1 ppm of reading + 0.02 μV). The resolution of the instrument in these two ranges is 0.1 μV and 0.01 μV respectively. In addition to its use in precision voltage measurement, the potentiometer can be used for standard cell comparisons.

b. The principle of operation of the potentiometer is based on a technique of direct current comparison developed at the National Research Council of Canada by N. L. Kusters.

c. Inherently this technique eliminates many of the error sources present in conventional measurement systems which depend on precision resistors. The instrument therefore offers accuracy, stability, and linearity which is at least an order of magnitude greater than that available in conventional designs.

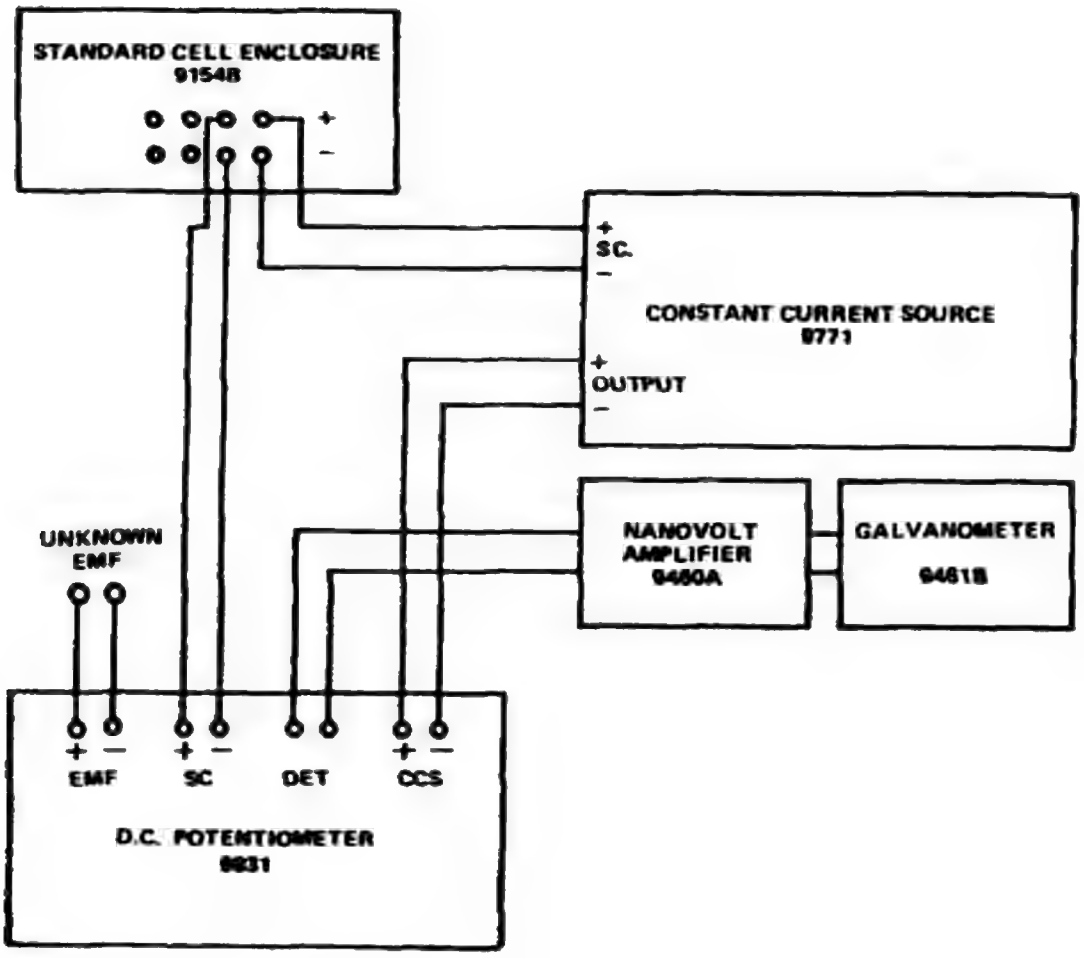


Figure 2-1. Interconnections cabling

2. Specifications.

Range factor:	X1	XO.1
Range:	O to 2.111,111,O V	O to O.211,111,10 V
Resolution:	O.1 μV per step	O.O1 μV per step
Accuracy:	±(O.5 ppm of reading + O.O5 μV) ±(1 ppm of reading + O.O2 μV) (plus uncertainty of reference standard cell)	
Polarity:	Reversible	
Linearity of measuring dials:	± O.O5 ppm of full scale	
Stability of measuring dials:	± O.O1 ppm of full scale reading per year	
Thermal EMFs:	Not greater than O.O2 μV	
Standardizing resolution:	O.1 ppm of standard cell value	
Dimensions:	20 1/4 in long x 9 7/8 in deep x 8 1/4 in high (51.2 cm x 24.O cm x 24.O cm)	
Weight:	40 lbs (18.2 kg) net 60 lbs (27.3 kg) shipping	
Power requirements:	105 - 125 Vac, 50/60/400 Hz, 50 VA	
External readout:	Available from multipin connector at bottom of instrument for connection to digital display.	

3. Mechanical installation. The potentiometer and its accessories should be located on a solid bench which is free from heavy vibration. The instrument should not be located in positions where it might be subjected to fluctuating heating or cooling. Locations near heating ducts, in front of windows subject to direct sunlight, or where cold drafts exist, are areas which should be avoided.

a. The galvanometer and amplifier used with the potentiometer should also be placed on a stable bench with the front panel controls readily accessible. It is preferable to locate the galvanometer system on other than the working surface and behind the potentiometer, with the scale slightly below eye level. Connection and checkout of the Model 9931 galvanometer and amplifier system should be performed according to the instructions detailed in their respective technical manuals.

b. The CCS should be placed on the working surface to allow connections to be conveniently made.

4. Operation. Remember to use solid copper wire when making connections to any external instruments or voltage sources. Stranded or tinned wire or lugs should not be used. Every precaution should be taken to avoid temperature variations when a measurement is being performed. Instruments should be carefully and neatly connected to prevent accidental short circuits during measurement. Special care should be taken to prevent short circuits of the standard cell and current source.

CAUTION

DO NOT DISCONNECT THE POTENTIOMETER LINE CORD WITHOUT FIRST DISCONNECTING THE CCS.

This is particularly important, otherwise the core will become temporarily magnetized and zero readings will have to be checked for several days.

a. Controls and indicators. All operating controls, indicators, and terminals are mounted on the front panel of the potentiometer as shown in Figure 2-2, and have the following functions:

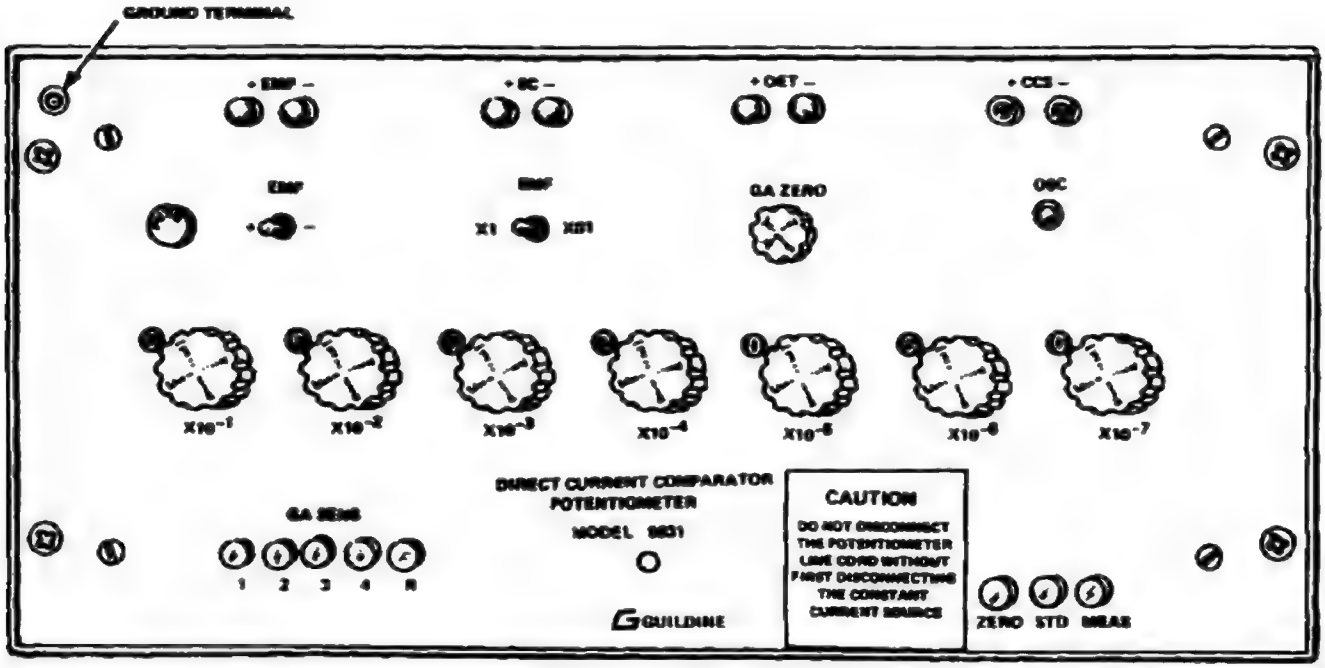


Figure 2-2. Front panel layout, Model 9931

(1) +EMF - This 2-position switch is of the locking toggle type (i.e., pulling on the switch arm unlocks it and allows the switch position to be changed) and serves to reverse the connections to the CCS terminals, and hence reverses the output voltage from the potentiometer.

(2) X1 - EMF - X0.1 This 2-position switch is of the locking toggle type (i.e., pulling on the switch arm unlocks it and allows the switch position to be changed) and serves to change the measuring range of the potentiometer. The range is 0 to 2.111,111,0V with the switch in the X1 position and 0 to 0.211,111,l0V with the switch in the X0.1 position.

(3) GA ZERO. This continuously variable control is used to introduce a back-off voltage which compensates for any thermal EMFs in the measuring circuit.

(4) OSC. This lamp is connected to the modulator output and will be illuminated during normal operation. An ampere-turn overload in the current comparator will cause the lamp to become extinguished.

(5) Measuring dials. These seven dials set the potentiometer output voltage in increments as shown in Table 2-1. Each dial has 11 positions (dial No. 1 has 21 positions) and the position numbers appear in the window at the side of each dial.

DIAL NUMBER	LEGEND	NUMBER OF STEPS	VOLTAGE INCREMENT PER STEP X1 RANGE	VOLTAGE INCREMENT PER STEP X0.1 RANGE
1	$X10^{-1}$	20	0.1	0.01
2	$X10^{-2}$	10	0.01	0.001
3	$X10^{-3}$	10	0.001	0.000,1
4	$X10^{-4}$	10	0.000,1	0.000,01
5	$X10^{-5}$	10	0.000,01	0.000,001
6	$X10^{-6}$	10	0.000,001	0.000,000,1
7	$X10^{-7}$	10	0.000,000,1	0.000,000,01
		MAXIMUM VOLTAGE	2.111,111,0	0.211,111,10

Table 2-1. Measuring dials

(6) GA SENS. This is the row of five pushbuttons, labelled 1 through 4, and R. Each button selects a progressively greater galvanometer sensitivity (number 4 being the most sensitive); and the button labelled R reverses the galvanometer connections. Two dots are engraved on pushbutton number 1. When these dots are at right angles to the line of buttons, any button that is depressed remains depressed until another button is selected. When the dots are parallel to the buttons, all the buttons are spring return, and cancel automatically when released.

(7) ZERO pushbutton. When this button is pressed, the CCS is disconnected from the primary winding (i.e., zero ampere-turns) and the detector terminals are connected across the voltage-generating resistor. Thermal EMFs can then be balanced out by using the GA ZERO control. Two dots are engraved on this pushbutton. When these dots are at right angles to the line of pushbuttons, the ZERO, STD, and MEAS pushbuttons will remain depressed until another is selected. When the dots are parallel to the buttons, all the buttons are spring return, and cancel out automatically when released.

(8) STD pushbutton. This button is pressed when it is required to standardize the potentiometer.

(9) MEAS pushbutton. Pressing this pushbutton connects the potentiometer output to the EMF terminals and allows measurement of the unknown external voltage.

b. Terminals and connectors include the following:

(1) Ground. A chassis ground terminal is located on the front panel.

(2) + EMF - The voltage to be measured is connected to these terminals.

(3) + SC - These terminals are connected to a standard cell when standardizing the instrument.

(4) + DET - The galvanometer system is connected to these terminals.

(5) + CCS These terminals are connected to the CCS.

(6) Fuse. A 2A fuse is mounted on the front panel of the potentiometer.

(7) Line cord. The line cord is connected underneath the potentiometer.

(8) Readout socket. A multipin socket which mates with the connector from a Readout Display unit mounted underneath the potentiometer.

c. ZERO adjustment. Operation of the ZERO button connects the external detector across the voltage-generating resistor. It also disconnects the CCS from the primary winding and simultaneously reduces the slave power supply to zero current, thus producing nominally zero voltage across the generating resistor. Any thermal EMFs, however, will cause an output voltage which will be detected by the galvanometer. The effect of these thermal EMFs is eliminated by injecting a small current through the generating resistor to produce an equal and opposite EMF. The complete procedure would be carried out as follows:

(1) The ZERO pushbutton is depressed.

(2) The two dots on GA SENS key No. 1 are set perpendicular to the line of keys.

(3) The GA SENS key No. 1 is depressed, and using the GA ZERO control, the galvanometer reading is reduced to zero.

(4) The sensitivity of the galvanometer is increased by depressing GA SENS keys No. 2 through 4, and the galvanometer reading is readjusted to zero as required. (The detector itself should be set at its medium sensitivity by adjusting the gain of the Nanovolt Amplifier.)

(5) The GA SENS key R is depressed and any movement of the galvanometer is noted. The GA ZERO control is adjusted to give no detectable change of galvanometer reading when keys No. 4 and R are alternately depressed.

The galvanometer may not be at zero when the final balance is obtained, due to a thermal EMF or other zero offset in the detector itself. This is not important since input to the detector is reversed and only changes in the balance point are of significance.

d. Standardization.

(1) The system is connected as shown in Figure 2-3.

(2) An external saturated standard cell is connected to the terminals marked SC using solid copper wire which should preferably be twisted and shielded. To avoid the possibility of a reverse polarity connection or a short circuit of the standard cell, mark the wires before twisting and connect the potentiometer first. Ensure that the EMF switch is in the positive position.

(3) The Measuring Dials are set to the known voltage of the standard cell being used as a reference.

(4) The STD pushbutton is depressed, thus connecting the external voltage reference in series opposition to the voltage across the generating resistor.

(5) The 9771 Thumbwheels are set to approximately 5000.

(6) The GA SENS key No. 1 is depressed and the deflection of the galvanometer is noted. Adjust the current controls of the external current source to zero the galvanometer.

(7) The galvanometer sensitivity is increased by successively depressing keys No. 2 through 4 and continuously adjust the current source to

maintain the zero reading on the galvanometer. Final adjustment is made by ensuring that the galvanometer does not deflect when keys No. 4 and R are alternately selected.

The voltage across the generating resistor is now equal and opposite to the standard cell EMF and the potentiometer is standardized.

CAUTION

DO NOT OPERATE THE EMF REVERSING SWITCH WHILE THE STD PUSHBUTTON IS DEPRESSED, SINCE THE VOLTAGE FROM THE GENERATING RESISTOR WILL BE REVERSED, AND IF THE GA SENS KEYS ARE DEPRESSED, A CURRENT FLOW MAY DAMAGE THE STANDARD CELL.

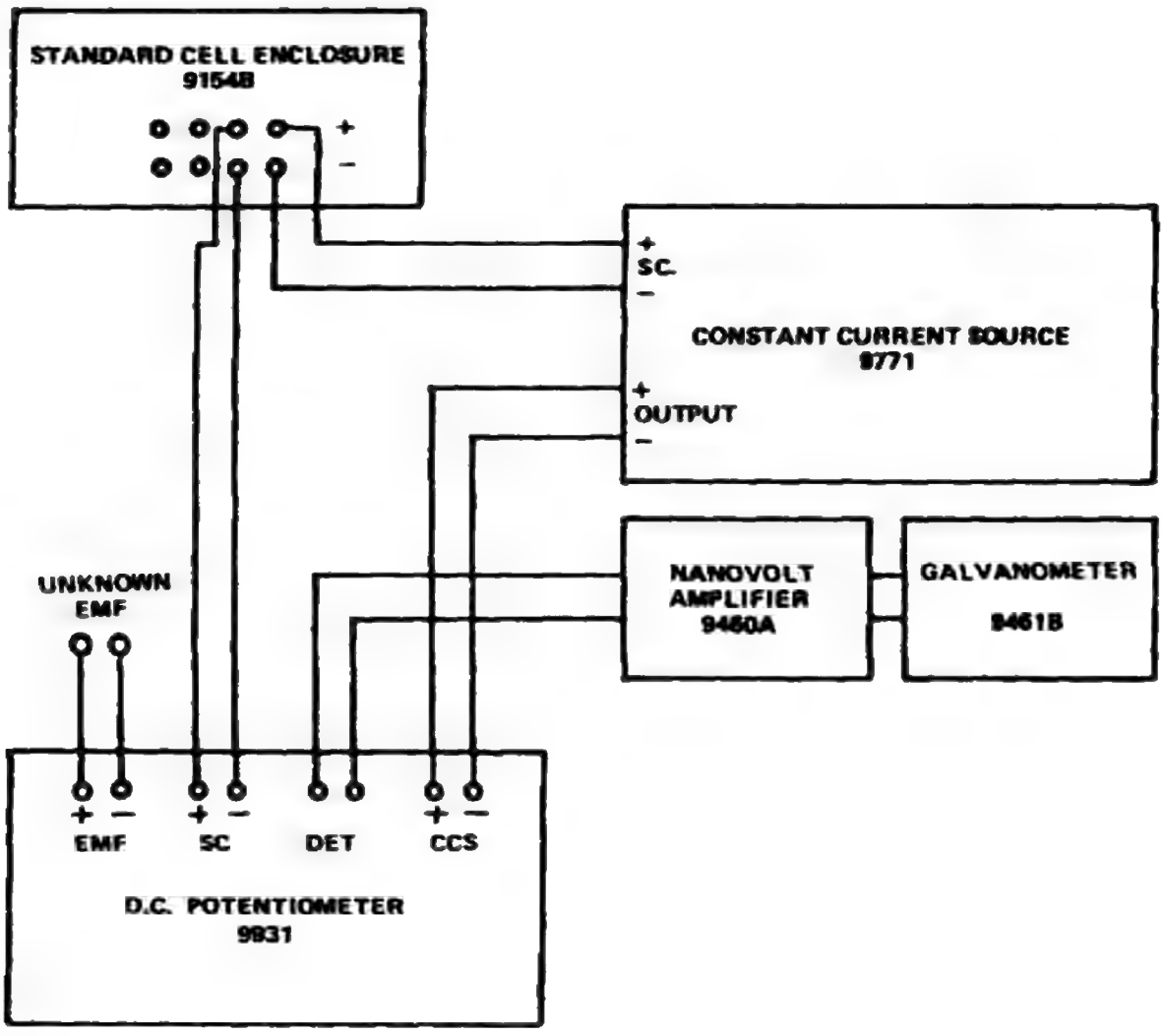


Figure 2-3. Connecting the system

5. Voltage measurement.

a. Between 0 and 2.1 volts.

(1) With the potentiometer standardized as outlined in the previous section, raise the GA SENS and the function keys ZERO, STD, and MEAS by turning keys 1 and ZERO until the dots lie in the vertical position. The +EMF switch should be in the positive position.

(2) The voltage to be measured is connected to the EMF terminals using untinned solid copper wire, preferably twisted and shielded. Set the Measuring Dials to the approximate value of the unknown voltage if possible.

(3) The range switch is set to the X1 position.

(4) To connect the EMF terminals to the generating resistor the ZERO key is rotated and the MEAS key depressed.

(5) The GA SENS key No. 1 is turned through 90°, depressed, and using the Measuring Dials, the galvanometer is zeroed.

(6) The sensitivity of the galvanometer is increased by depressing GA SENS keys No. 2 through 4 and readjusting the Measuring Dials to maintain the null on the galvanometer. Final null should be obtained by alternately depressing keys No. 4 and R and adjusting the dials to minimize any change in the galvanometer reading.

The measured voltage may now be read from the dials.

b. Between 0 and 0.21 volts.

(1) The procedure is exactly the same as that described in Subsection 3-5(a) above, except that the range switch is moved to the X0.1 position, and the zero adjustment procedure should be repeated if greater zero accuracy is required. For the greatest measurement accuracy on the X0.1 range, the potentiometer would be zeroed as outlined below.

(a) Connect the measuring leads to the Model 9931 and short-circuit them at their other end.

(b) Set all the EMF dials to read zero.

(c) Depress the MEAS function button.

(d) Adjust the GA ZERO control until there is no change in galvanometer deflection when the GA SENS keys 4 and R are successively depressed.

(2) This procedure eliminates the effect of thermal EMFs in the measuring leads to the known EMF.

6. Theory of operation. Figure 2-4 is a block diagram showing the major components of the potentiometer. The unknown EMF is compared with a known voltage generated by passing a known current through a stable-generating resistor. The current also passes through the secondary winding of a current comparator toroidal transformer, where it is compared with a stable 30 mA current in the primary.

a. The comparator circuit automatically adjusts the secondary current until the effects of the ampere-turns in the secondary and primary windings exactly cancel. In this condition, the ratio of secondary to primary currents is equal to the ratio of secondary to primary turns. The primary current is held constant by using a precision CCS while the number of turns on the primary winding may be discretely selected using a set of switches. The current in the fixed secondary winding, which depends on the turns ratio between primary and secondary, may therefore be precisely controlled by switching the appropriate number of turns into the primary winding.

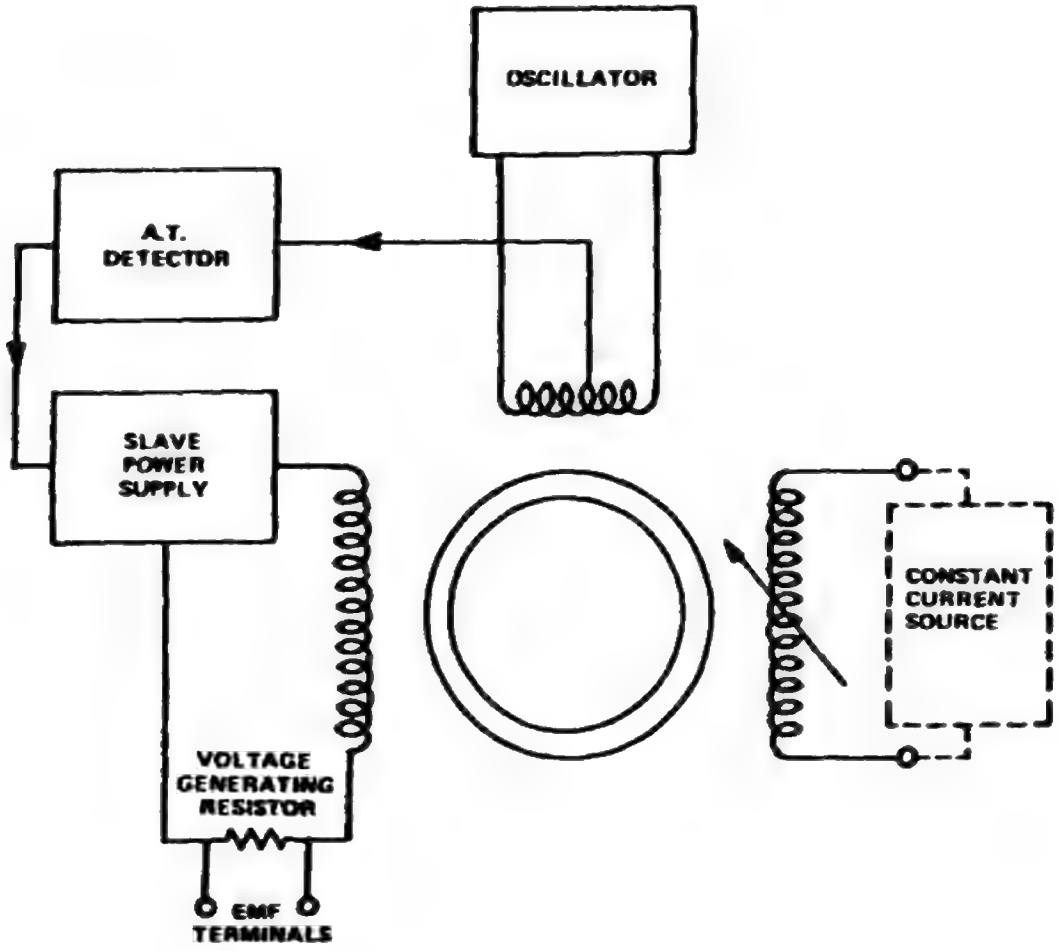


Figure 2-4. Block diagram of potentiometer

b. A resistor (known as the generating resistor) is placed in series with the secondary current and the voltage which appears across it may be

raised to balance the unknown voltage. The balance point is detected by means of a galvanometer in series with the two opposed EMFs.

c. Thus, the potentiometer stability and linearity depend on a stable fixed resistor, a stable CCS source and a transformer turns ratio. It is therefore inherently more accurate than conventional potentiometers which rely on the stability and linearity of variable resistors.

d. The secondary current is set by the combination of a tracking amplifier and a slave amplifier. The tracking amplifier monitors the voltage across the primary turns ratio times the primary current. Fine adjustment is provided by the slave amplifier which varies the current until the flux in the current comparator transformer is zero (i.e., the ampere-turns in the primary and secondary windings exactly cancel). The zero flux condition is sensed by two high permeability cores mounted within the shield of the toroidal transformer. The windings on these cores are connected in series opposition and the cores are driven into saturation by a square wave oscillator. Any dc flux in the toroidal transformer core causes one sensing core to saturate slightly before the other and results in a modification of the output voltage pulses at the junction of the two windings. A peak detector circuit converts these voltage pulses at the junction of the two windings. A peak detector circuit converts these voltage pulses into a dc signal whose magnitude and polarity are proportional to the magnitude and polarity of the flux in the toroidal transformer core. This dc signal then drives the slave amplifier in such a manner as to reduce the flux level to zero.

7. Factors contributing to accuracy.

a. GA ZERO. Any thermal EMFs in the measuring circuit will appear in the output of the potentiometer. These spurious EMFs are compensated for by the GA ZERO control which introduces a current in the secondary winding and produces an equal and opposite EMF across the generating resistor. The current is introduced in such a manner that it does not interfere with the ampere-turns balance of the current comparator. As the net thermal EMF will be of one polarity, the indication that it has been exactly cancelled is that the galvanometer reading does not change when the currents in the potentiometer are reversed. The GA ZERO control is adjusted until this condition prevails.

b. Generating resistor. The generating resistor is designed to have an extremely low power coefficient so that it makes only a small contribution to nonlinearity as the secondary current is increased from 0 to 200 mA.

c. Fractional turns. The effect of fractional turns for the fourth dial is produced by a resistive divider which diverts l/l0th of the primary current to a switched 10-turn winding. Each step of the fourth dial switches 1/l0th of the current produced by each step of the third dial. The accuracy required of this 10:1 current division is only 1 part in 10^3 of the accuracy

of the first dial. Thus, to ensure an accuracy of 1 part in 10^7 of full scale, the resistor accuracy need not be better than 10^4 (or 0.01%). During manufacture, the ratio is adjusted to ±0.001% and the construction is such that a drift rate of not more than 0.01% per year may be expected. This is equivalent to 0.01 μV/step of the fourth dial per year.

The total range of the fifth, sixth, and seventh dials is produced by similar current dividing resistors, but with accuracy requirements of 0.1%, 1%, and 10%, respectively. The errors of the resistive divisions apply only to the dial totals, and not to the linearity of the dials which still depends on the equality of the 10 turns and is the same for all dials. An internal trimmer is provided to correct for any long term drift.

d. Measuring circuit thermal EMFs. The only components in the measuring circuit are the generating resistor, the low thermal pushbutton selector switch, and the galvanometer circuit (with low thermal keys). There are no Measuring Dial contacts in the measuring circuit. The design and construction of this part of the circuit incorporates the best low thermal techniques, with heavy thermal insulation and large heat sinks. Thermal EMFs of a few nanovolts exist only when relatively large and rapid variations in room temperature create temperature gradients as heat flows into or out of the potentiometer.

e. Switch contact resistances and contact EMFs. In the potentiometer, all Measuring Dial contacts are in circuits of at least 1000 megohms resistance and variations in contact resistance or generated thermal EMFs at these contacts are therefore negligible.

f. System noise. The resolution of the potentiometer is limited by system noise rather than the number of turns or the Measuring Dials. This noise is about 1 μAT and since the comparator is operated at an ampere-turn level of about 30AT, the 1 μAT of noise is therefore equivalent to 0.033 μV on the X1 range and 0.0033 μV on the X0.1 range.

Learning Event 2:
DESCRIBE THE MODEL 9771 CONSTANT CURRENT SOURCE (CCS)

1. Functional description. The Guildline Instruments CCS Model 9771 is designed to serve as a long-term working reference for precise electrical measurements. With an output current of 30 mA ± 10% and regulation of better than 1 ppm, the CCS is an ideal replacement for the conventional lead-acid battery usually used with a DC Potentiometer. High current stability is achieved by using a galvanometer light beam-photo transistor amplifier combination to compare the voltage produced across a stable resistor with the voltage of an external standard cell. The circuit gain is so high that an output resistance greater than 10^9 ohms is achieved. Regulation is better than 1 ppm for a 1000-ohm change in load resistance, and better than 1 ppm for a 5% change in line voltage. Four thumbwheel switches and a fine control enable the operator to set the output current accurately to any point within the operating range.

2. Specifications.

Output current:	30 mA ±10%, continuously adjustable
Voltage compliance:	35 V
Output resistance:	10^9 ohms, or greater
Load regulation:	Better than 0.1 ppm for 100-ohm change in load resistance
Line regulation:	Better than 1 ppm for 5% change in line voltage
Stability:	1 ppm/24 hrs + external standard cell instability
Isolation from line:	10^9 ohms, or greater
Power requirements:	105-125 Vac, 50/60/400 Hz, 35 VA
Dimensions:	6 1/2 in wide x 7 1/2 in high x 13 in deep (16.5 cm x 19.0 cm x 33.0 cm)
Weight:	19 lbs (8.6 kg) net 26 lbs (11.9 kg) shipping

3. Installation. The CCS should be placed in a convenient position on a firm, level surface which is free from vibration. It should be located close to the equipment with which it will be used (for example, a potentiometer and/or standard cell enclosure), so that the operating controls may be easily reached.

4. Initial setup and electrical checks. When using the instrument for the first time, and before making any electrical connections, turn the instrument through 90° onto its left side, then return it to the normal upright position. This procedure will remove any air bubbles in the galvanometer damping fluid that may have become trapped behind the lens during shipment.

5. Operation. No special precautions are required when operating the CCS; however, it is recommended that, in order to minimize thermal EMFs, only solid pure copper wire be used for all connections. Guildline Instruments SCW wire is ideal for this purpose. Stranded or tinned wire, or lugs, should not be used.

a. Controls and indicators (fig 2-6).

(1) Current controls. Four thumbwheel switches provide a coarse current adjustment and a 10-turn variable control provides a fine adjustment. Note that the thumbwheel switches are not calibrated directly in terms of

current but serve only as a logging facility in order to permit the instrument to be reset to a particular current. If desired, a chart or graph may be prepared of current versus switch setting.

(2) OFF-CURRENT-ON. This rotary switch has three positions which give: CURRENT circuit OFF, CURRENT circuit on, and galvanometer lamp ON. The three positions are provided so that application of power to the current circuit, and illumination of the galvanometer lamp always occur in the correct sequence.

(3) OVERLOAD indicator. This lamp is illuminated whenever the overload relay becomes de-energized and disconnects the standard cell from the current control circuitry. The current is not controlled when the OVERLOAD lamp is illuminated.

(4) Galvanometer zero adjust. This knob is located on the side of the CCS and is used to center the light spot on the photo transistors (fig 2-5).

(5) Viewing port. A small hole in the front panel immediately below the thumbwheel switches enables the operator to view the position of the galvanometer light spot.

(6) Fuse. A 2A line fuse is located on the front panel of the instrument.

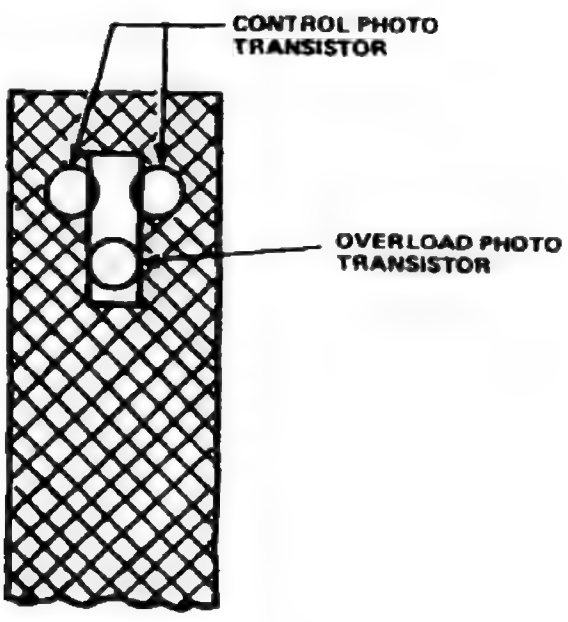


Figure 2-5. Light spot position

b. Terminals.

(1) SC terminals. These terminals are for connection to the standard cell. Correct polarity is indicated by the "+" and "-" engraved next to the positive and negative terminals respectively.

(2) CURRENT terminals. The output current from the CCS appears at these terminals. The voltage at the red terminal is positive with respect to the black terminal.

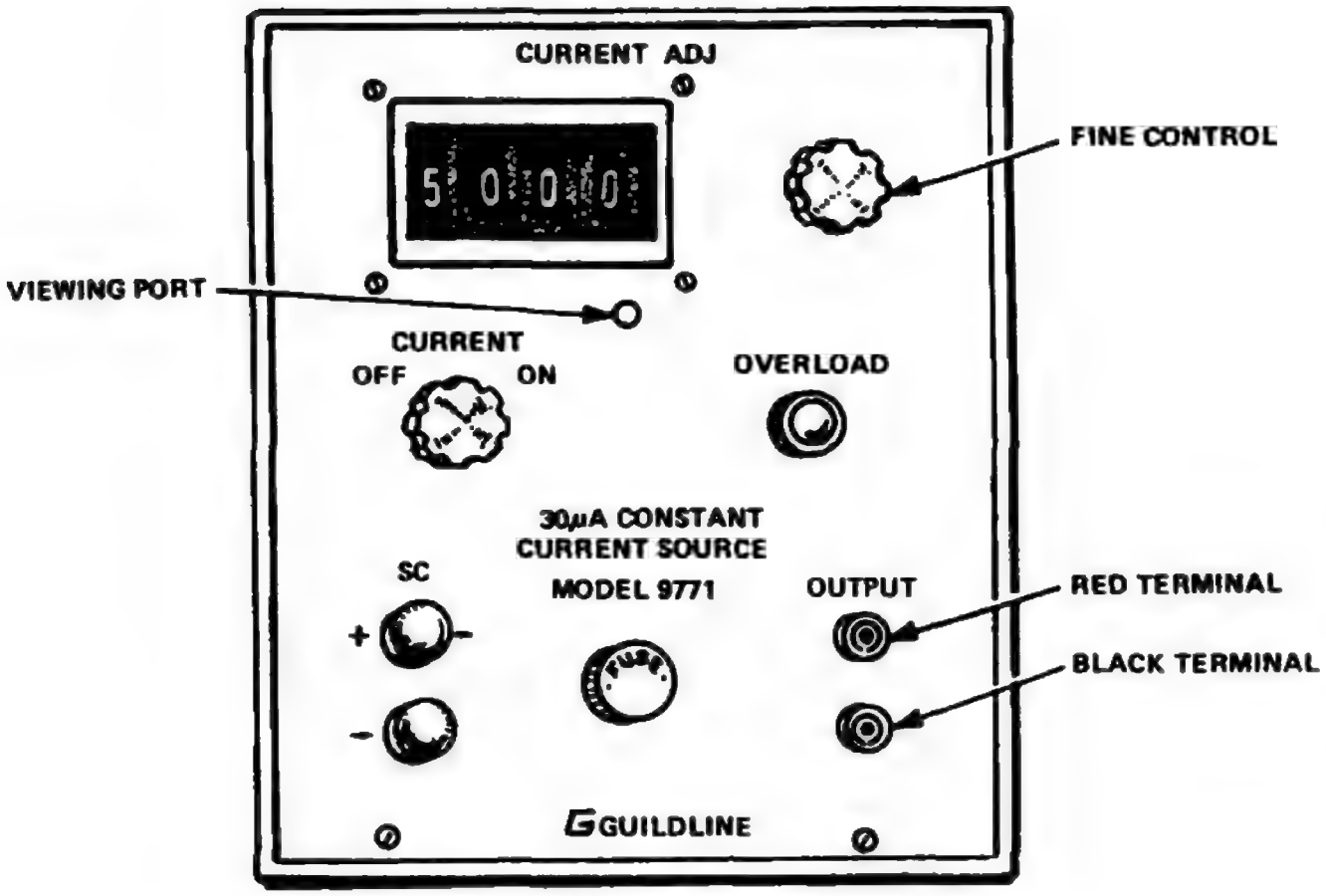


Figure 2-6. Front panel layout Model 9771

6. Theory of operation. The principle of operation is illustrated in Figure 2-7. The line supply is transformed, rectified, and smoothed to give a dc supply at approximately 35 volts. Current from this source flows in the loop, consisting of the variable resistor, the load, and a light-sensitive amplifier which functions as a light-actuated variable resistance. The voltage developed across the variable resistor is arranged to be approximately 1.018 volt for all current values within the range of the instrument. This voltage is connected in series opposition to a saturated standard cell and any difference

voltage is detected by the Galvanometer (G). Light from the galvanometer mirror falls on a pair of photo transistors, which, depending on the amount of illumination received, control the current in the loop. A continuous correction to the current value is thus applied in the presence of changes in line voltage and load resistance.

a. Control circuit. Normally, the voltage across the variable resistor is equal to the standard cell voltage, and no current flows in the galvanometer. Any change in the current causes a change in the voltage across the variable resistor, and allows current to flow in the galvanometer. The resulting displacement of the galvanometer mirror, away from its center position, causes a change in the light-dependent transistors which alters the current so as to return the mirror to its center position. Thus there tends to be zero current flow in the galvanometer circuit and the voltage across the variable resistor is kept equal to the standard cell voltage.

Because of the very high gain in the current control circuit, the output resistance of the CCS is greater than 10^9 ohms, therefore a change in the lead resistance of 100 ohms will result in a current change of only 0.1ppm. The output terminals can be open or short-circuited indefinitely without damage to any components. An increase in load resistance to a value that produces an output voltage of 30V or more will cause the bypass circuit to operate and the current will cease to be controlled.

b. Overload relay. The function of this relay is to protect the standard cell from current overload. Normally, the relay is continuously energized by a circuit which detects that the galvanometer light spot is correctly positioned. A photo transistor is positioned so that it is illuminated only when the light spot is correctly positioned over the two control photo transistors. When the overload relay is energized, the standard cell is connected into the galvanometer circuit. If the galvanometer lamp should burn out, the photo transistor will not be illuminated, the overload relay will release, and the standard cell will be disconnected. Similarly, if an external standard cell should be connected in the wrong polarity, the galvanometer light beam will be violently deflected away from the photo transistor, thus disconnecting the standard cell. The OVERLOAD lamp is illuminated whenever the overload relay is released.

c. Bypass circuit. When the voltage across the load exceeds 30V, a zener diode bypass circuit operates and takes all or part of the output current. Therefore the terminals can be open circuited, and no damage will occur.

d. Standard cell. An external standard cell is used as a reference with the CCS. The gain of the control circuitry is such that a 20% change in load current is produced by a 10^2 μA change in the galvanometer (and hence standard cell) current, and typical changes in load resistance during operation produce standard cell currents of only a few picoamperes. The characteristics of a standard cell are such that this current can be taken for many hours without significant change in the standard cell voltage.

e. The variable resistor shown in Figure 2-7 is, in practice, the four thumbwheel switches and the fine current control. These provide the necessary resolution and resetability to allow the selection of any desired current from 27 to 33 mA.

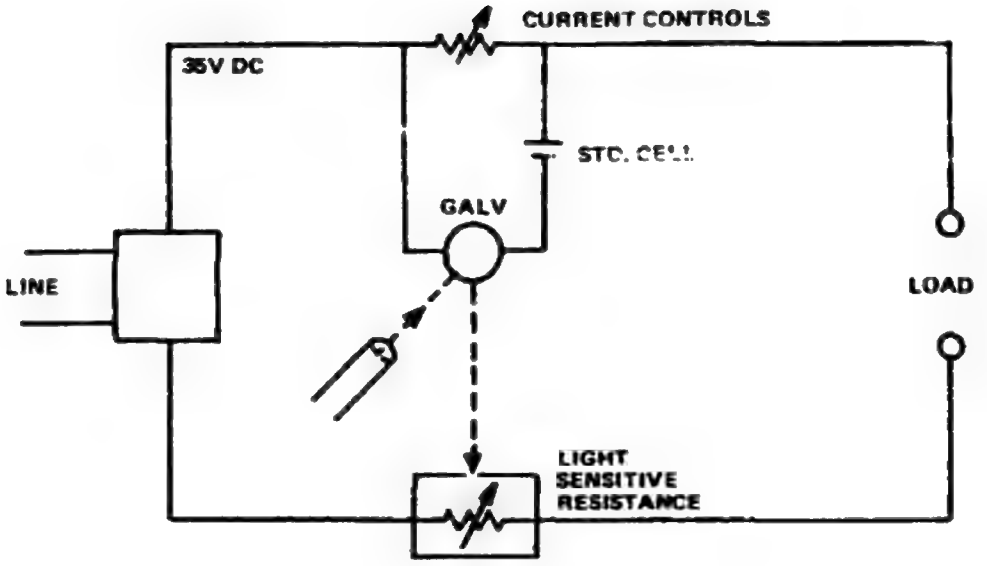


Figure 2-7. Simplified schematic diagram

Learning Event 3:
DESCRIBE THE MODEL 9460A NANOVOLT AMPLIFIER

1. Functional description. The Model 9460A Nanovolt Amplifier is designed for amplifying very low level dc signals of nanovolt and nanoamp levels.

a. The output is linear over the operating range and can be used to drive most potentiometric recorders or digital voltmeters.

b. Because of its high current sensitivity, it is ideally suited for operation as a null detector when used in conjunction with the Guildline Model 9461A Secondary Galvanometer or other null indicators. An important feature of the Model 9460A is that the polarity of the input signal may be reversed in order to balance out parasitic or thermal EMF in the measured circuit. In this respect the amplifier is much superior to electronic detectors employing ac amplifiers. The detector element is heavily damped and does not respond to transients or frequencies higher than a few Hertz.

c. To avoid instability or zero drift, precautions have been taken to eliminate temperature gradients across junctions of dissimilar metals. A high insulation resistance is maintained with near infinite common mode rejection and the copper input output terminals are shielded from air currents by a removable cover to reduce the generation of thermal EMFs.

d. A gain control varying the amount of feedback provides the facility for calibrating the amplifier to output indicator or recorder.

2. Specifications.

2. Specifications.

	Series Gain (Voltage Amp)		Parallel Gain (Current Amp)	
	Min	Max	Min	Max
Sensitivity:				
a. As an amplifier - 10KΩ load resistance	0.5μV/nV	15μV/nV	10μV/nA	300μV/nA
b. As a detector - with Model 9461A or 9462A Secondary Galvonometer	0.1nV/nm	3nV/nm	20μV/nm	600μV/nm
Input resistance:	3.6KΩ	120Ω	2Ω	2Ω
Maximum input (10KΩ load resistance):	20μV	0.6μV	10μA	0.3μA
Response time at 100Ω source:	1 sec	2.7 sec	1 sec	2.7 sec
Stability: less than	6nV/hr	200nV/hr	3nA/hr	100nA/hr
Linearity (1 ohm source resistance):	±1%	±5%	±1%	±5%
CMR (db @ 60Hz) greater than	240			
NMR (db @ 60Hz) greater than	120			
DC isolation	$10^{12}\Omega$			
Recorder output (into 10KΩ max)	10-0-10μA (100mV-0-100mV)			

Terminals: Input and output, low thermal copper.
Ground (case)

Controls: GAIN (continuous) and ZERO

Construction: Aluminum cover and panel mounted on phenolic baseplate

Dimensions: 5 7/8 in x 6 1/8 in x 12 in (15 cm x 16.5 cm x 33 cm)

Weight: 11 pounds (5 kg)

Power: 6 volts ac/dc 6 watts
(supplied from Model 9461A Secondary Galvanometer)

3. Installation. The Nanovolt Amplifier should be mounted in such a position that it is not subject to vibration. The front panel controls, (fig 2-8), and the inspection port on the left-hand side, (fig 2-9), should be accessible.

a. Input connections. The terminal cover plate may be removed after unscrewing the knurled retaining screw. The copper link should be connected between the terminals marked SERIES FEEDBACK or PARALLEL FEEDBACK according to choice and the input connected to terminals 1 and 2 with output from terminals 3 and 4. The characteristics of the two modes of operation are listed below:

(1) Parallel feedback: This connection is predominantly useful when the amplifier is to be employed as a null detector in bridge and potentiometer work. The amplifier has a constant input impedance of approximately 2Ω. The maximum inputs that can be applied are as follows:

	Max Input	Max Output (dependent on load resistance)
Gain at Min	50 μA	150 μA
Gain at Max	1.6 μA	50 μA

When greater sensitivity is required, the input connection can be made to terminals 1 and 3 instead of terminals 1 and 2. This bypasses the 2Ω series resistor and reduces the input impedance to between 0.01Ω and 0.2Ω from minimum to maximum gain. This connection is useful when working from low impedance circuits.

(2) Series feedback. This connection is primarily for applications where the Model 9460A is to be operated as a linear voltage amplifier to drive a potentiometer recorder or digital voltmeter. It is also used in high impedance circuits for null detection. The maximum inputs that can be applied are as follows:

	Max Input	Input Impedance	Max Output	(dependent on load resistance)
Gain at Min	25 μA	3.6KΩ	150 mV	
Gain at Max	0.83 μA	120 Ω	50 μA	

(3) The input circuit of the amplifier comprising the galvanometer leads, terminals, and connections to the feedback components, is completely of copper construction in order to avoid parasitic voltages. It is desirable that this principle be continued throughout that part of the input circuit external to the amplifier. The use of twisted pairs of bare untinned copper wire with high quality insulation is recommended. Tinned or stranded wire should be avoided. A length of suitable twisted shielded wire (Guildline Type SCW) is supplied with the instrument.

(4) The terminal cover plate should always be in position when the amplifier is in use in order to avoid drafts which may produce thermal EMFs at the input terminals. The input and output leads should be accommodated in the

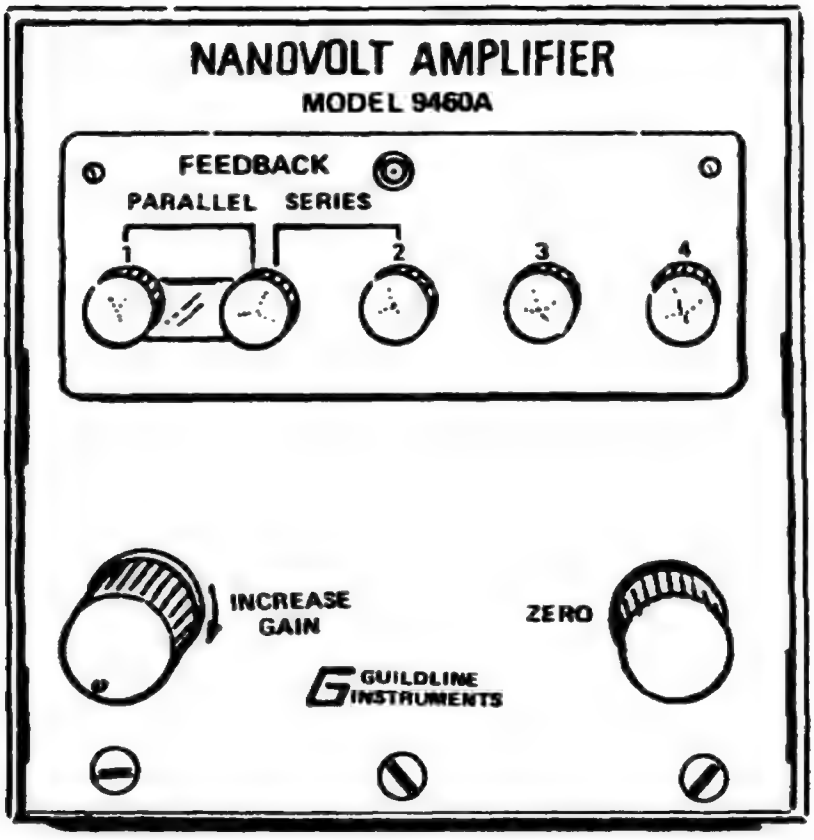


Figure 2-8. Front panel layout

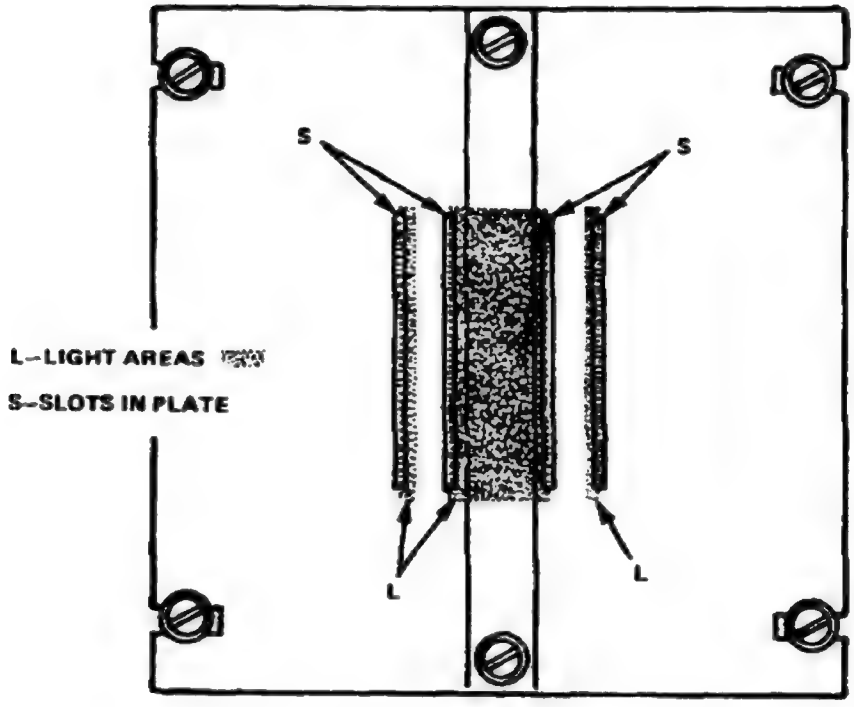


Figure 2-9. Model 9460A-light pattern

slots provided in the cover plate. The GND terminal at the rear of the instrument should be connected to a low resistance ground point.

(5) The lamp power cable is connected to the 2-pin connector on the left side of the Model 9461A Secondary Galvanometer.

b. Output connections. The amplifier has a very high output impedance and the output current is independent of load resistance up to the point where the output voltage exceeds approximately 150 mV, at which point the amplifier overloads.

(1) When the amplifier is to be used in conjunction with a high input impedance recorder or indicator it is necessary to reduce the input impedance by shunting with an appropriate resistor. A chart of the input-output characteristics versus load resistance is shown on Figure 2-10. From this chart the shunt resistor most suitable for the application can be determined.

(2) When the instrument is to be used as a voltage amplifier and is to have the minimum loading effect upon the source, the amplifier gain should be set at minimum where the input impedance is highest (approx. 4.7Ω).

(3) Calibrating the indicator scale for a known input to the amplifier can be achieved by using an adjustable shunt resistor instead of adjusting the amplifier gain control.

(4) Since the amplifier has a common line between the input and output circuits, the output recorder or indicator should have a high common mode rejection ratio if applicable. (Guildline Model 9461A has been designed specifically as an indicating galvanometer for use with the Model 9460A Amplifier.)

4. Operation.

a. Initial zero procedure. One of the leads from the indicating galvanometer is temporarily removed and the mechanical zero controls are adjusted to zero the light spot. The inspection port on the left-hand side of the amplifier is uncovered and the amplifier zero control is adjusted as necessary to make the two illuminated vertical strips coincident with the two vertical slits in the mask of the photo cell unit (fig 2-9). The final adjustment should result in the light strips being slightly offset inwards. The indicating galvanometer is recommended and the cover is replaced over the inspection port.

(1) The zero control is readjusted so that the indicating galvanometer registers null deflection.

(2) The above procedure will be facilitated if the INCREASE GAIN control is set near maximum feedback (approaching full anticlockwise rotation). The INCREASE GAIN control should be adjusted as necessary to obtain the

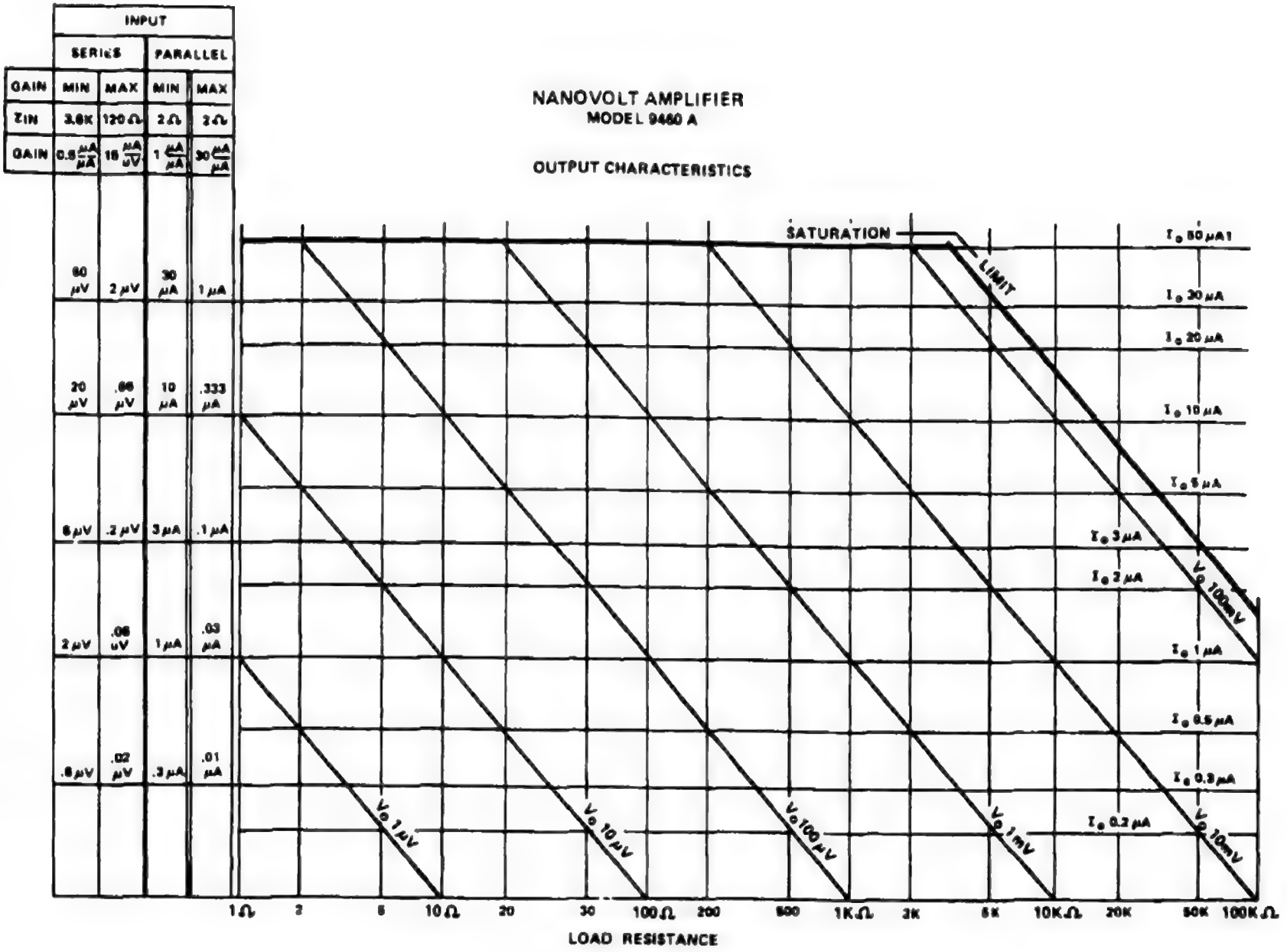


Figure 2-10. Input/output versus load resistance

required sensitivity and stability. Clockwise rotation of this control will reduce feedback and increase sensitivity.

(3) A change in the zero position on the indicating galvanometer is usually caused by an offset in the amplifier. Correction of such a change should be made with the zero control on the amplifier - not that on the indicating galvanometer. If the reverse procedure is used, changes in either the gain control position or the sensitivity switch on the indicating galvanometer will result in further changes in the position of the galvanometer zero.

b. Additional adjustments. The optical system is factory adjusted so that the light strips will fall on the photo cell mask slits when the amplifier ZERO control is set to its midposition. After transportation, or after a heavy overload, it may be found that coincidence can no longer be obtained by any adjustment of the control. In this event, the cover of the instrument may be lifted off after removing the four screws along the bottom edge of the sides of the case. Set the ZERO control to the midposition of its travel and loosen the three screws holding the disc upon which the suspension is mounted. The galvanometer suspension and magnet assembly can then be rotated on its central pivot until the light strips are coincident with the slits in the photo cell mask.

5. Theory of operation. The Model 9460A Nanovolt Amplifier is housed in a metal case provided with a terminal for ground connection. A light source is mounted on the rear panel and the light is focused onto the mirror of a highly-sensitive galvanometer suspension. The suspension is oil-filled to reduce the effects of mechanical vibration and is mounted between the poles of a powerful magnet which can be rotated upon its insulator base to provide coarse zero adjust.

a. The light from the suspension is reflected onto a mirror which is rotated by a fine zero control on the right side of the front panel. The light source is masked leaving three adjustable slits. The strips of light are reflected through the optical system as shown in Figure 2-11 onto two photo cells. The photo cells are also masked leaving two slits in front of each cell. The slits are arranged so that the light strips illuminate only half the width of each slit. In this condition, the output of the two photo cells is equal. Any change in position of the pattern of light falling on the photo cell mask due to galvanometer deflection causes a large increase in the output of one photo cell and a similarly large decrease in the output of the other photo cell.

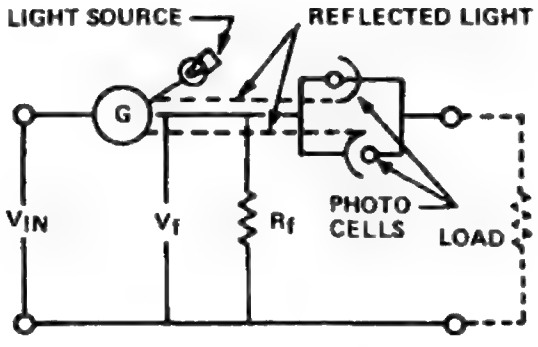


Figure 2-11. Simplified optical system

b. The two photo cells are connected in parallel opposing and the voltage appearing across the combination is zero when the cells' output are equal. When the cell outputs are unbalanced there is a current across the combination

which is fed through output terminals mounted on the front panel and this current is used to drive the external indicator and at the same time to provide negative feedback via a gain control mounted on the left side of the front panel.

c. Input terminals on the front panel are coupled with a link to a third terminal that connects the feedback circuit in either series or parallel.

Learning Event 4:
DESCRIBE THE MODEL 9461A GALVANOMETER

1. Functional description. The Model 9461A as shown in Figure 2-12 is termed a "Secondary" Galvanometer, as it is designed primarily for use with a Model 9460A Nanovolt Amplifier. The cabinet is formica and has a hinged top cover. Dimensions are 13 1/2 inches wide by 10 1/2 inches front to rear by 7 1/4 inches high. Weight is approximately 11 pounds. The scale is polarized to overcome the effects of ambient light and is backlighted so that the entire scale may be easily observed.

2. Specifications.

Sensitivity:	500mm/μA or 0.002μA/mm (mm = millimeter)
Input resistance:	550 ohms
Display:	240mm zero center scale with 3/4-inch diameter light spot, backlighted, polarized filter
Sensitivity ranges:	1/1, 1/10, 1/100, 1/1000 of full sensitivity
Period:	2.5 seconds
Terminals:	Input, low thermal copper Ground terminal
Connectors:	Two-pin for lamp supply Model 9460A Nanovolt Amplifier
Construction:	Formica-finished case
Dimensions:	13 1/2 in x 10 1/2 in x 7 1/4 in (34 cm x by 27 cm x 18.5 cm)
Weight:	11 lbs (4.5 kg)
Power:	120 volts ac/dc 12 watts (includes power to Model 9460A lamp)

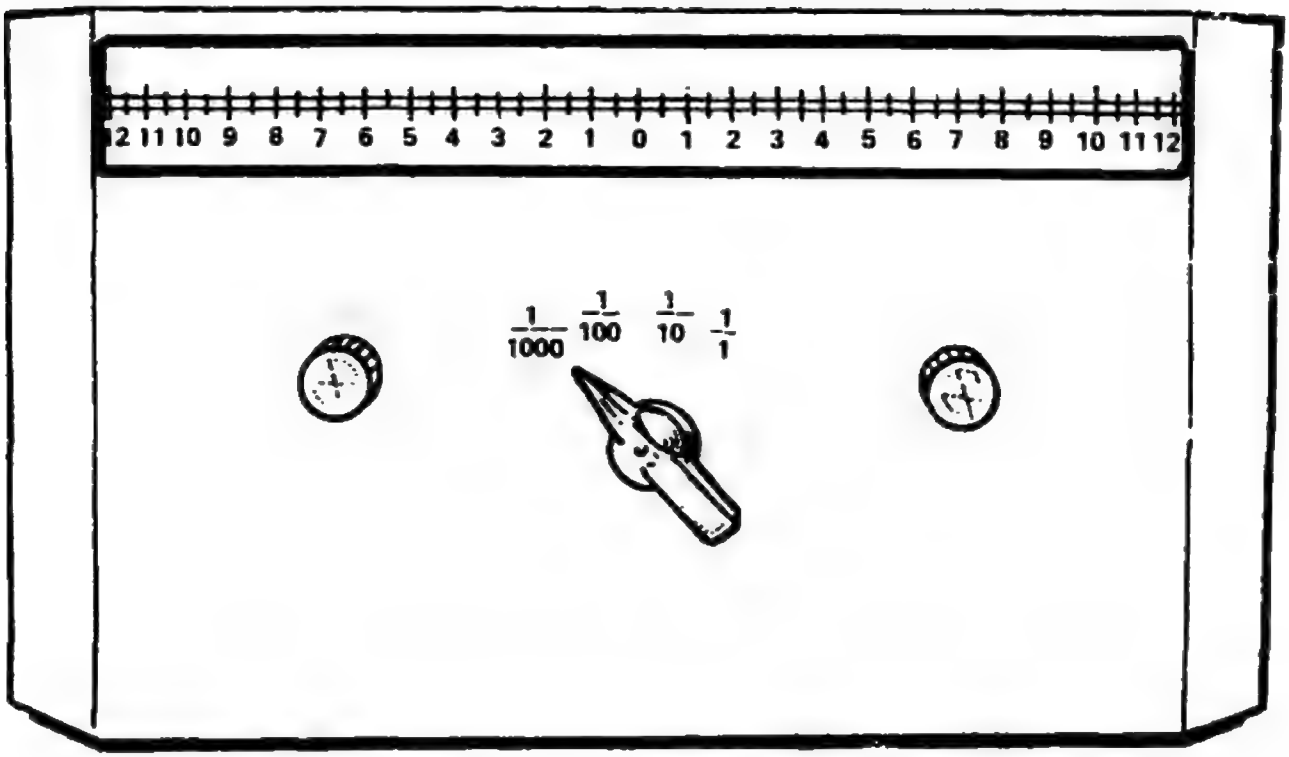


Figure 2-12. Front panel layout of Model 9461A Galvanometer

3. Installation. The Model 9461A should be installed on a shelf in front of the operator at approximately eye level.

a. The Model 9460A Nanovolt Amplifier lamp power cord is connected to the two-pin connector on the left side of Model 9461A.

b. The line cord is connected to a line supply of 120 volts, 60 Hz, and the galvanometer lamp is turned on by rotating the ON-OFF switch on the left-hand side of the front panel clockwise. A 3/4-inch light beam spot with a vertical hairline should appear on the scale. If it is greatly deflected, or off scale, the zero knob on the suspension should be adjusted to give an approximate zero, and the front panel zero will then provide a range of adjustment of about 90mm. (Before adjusting the suspension zero, note whether the mirror mounted on the inside rear of the cabinet is approximately parallel to the rear panel.)

4. Operation.

a. Controls.

(1) A front panel switch provides four decades of sensitivity increasing from 1/1000 to 1/1 for use in initial balancing operations. At the

most sensitive position (1/1) sensitivity is 500mm/μA (0.002μA/mm). The nominal galvanometer resistance is 550 ohms.

(2) ON-OFF switch. This switches the galvanometer lamp only, and is not in the galvanometer circuit. It is located on the front panel to the left of the sensitivity switch.

(3) Zero controls. Two mechanical zeros are available, a coarse control mounted atop the galvanometer suspension, and a fine control on the front panel to the right of the sensitivity switch. The coarse control should require no adjustment except, possibly, at the time of installation.

(4) Terminals. Two binding posts are available at the rear of the right-hand side of the cabinet for connection to the Model 9460A Nanovolt Amplifier.

(5) Connectors. A two-pin female connector mounted on the left-hand side of the Model 9461A provides lamp power for the Model 9460A Nanovolt Amplifier.

b. Zero procedure (with Model 9460A Nanovolt Amplifier). When used with a Model 9460A Amplifier the galvanometer should first be mechanically zeroed with the sensitivity switch set at 1/1000 (least sensitivity). Then, with the sensitivity switch set at 1/1 (greatest sensitivity), the final zero should be achieved with the electrical zero control on the amplifier. If this sequence is not followed, the galvanometer zero will shift as the galvanometer is switched through increasingly sensitive ranges.

CAUTION

1. The suspension clamping screw need not be engaged if the galvanometer is hand-carried from one location to another. If it is to be shipped, however, the suspension should be clamped.

2. The galvanometer mirror is surface-aluminized and easily scratched. Should it become necessary to clean the mirror, lightly brush the surface with a loosely-held wad of lens tissue dipped in acetone, chemically pure (CP) grade.

Learning Event 5:
DESCRIBE THE MODEL 9154B STANDARD CELL ENCLOSURE

1. Functional description. The Transvolt Transportable Standard Cell Enclosure Model 9154R (fig 2-13) is a four-cell instrument that has been specifically designed for maximum convenience as a completely transportable EMF Transfer Standard. It is equipped with its own integral rechargeable battery,

its size and weight have been reduced to minimum, and all controls have been grouped on a front panel with a roll-down protective cover. An integral bail-style carrying handle, a rugged Formica case, and internal foam cushioning provide for convenient, safe hand-transportability; and optional, fitted, fiberglass shipping container provides protection from all normal shipping stresses on commercial carriers. When fully charged the batteries maintain control of the chamber temperature for at least two weeks at room-ambient temperatures.

2. Specifications.

EMF standard: Four invertible saturated standard cells (1.018000 ±50μV) with porous septa. Connections accessible at four isolated, unplated copper terminal pairs on front panel.

EMF limit of error: Guildline test report supplied to ±2 microvolts for each cell, referred to the legal standard of voltage as maintained by the National Research of Canada (NRC) and the US National Bureau of Standards (NBS). May be sent to NRC or NBS for report to ±1μV or better.

Internal temperature: 32°C ±0.2°C.

Temperature regulation: Within ±0.002°C for 24 hours in ambient temperature of 23°C ±-2°C.

Temperature stability: Drift less than 0.02°C for one year.

Temperature recovery: Drift less than 0.02°C after exposure to 0°C or 35°C for a period of 1 hour and within ±0.005°C when followed by 2 hours in an ambient temperature between 20°C and 28°C.

Temperature monitoring: Independent internal thermistor bridge connects via front panel terminals to external null detector (not furnished).
Range: ±0.025°C
Resolution: 0.001°C
Drift less than ±0.01°C per year.

Overtemperature protection: Bimetallic sensor shuts down control circuit and activates OVERTEMP indicator on the front panel when the inner chamber temperature exceeds 35°C ±2°C.

Front panel indicators: AC ON lamp
Meter indication of heater cycling
Meter indication of battery state of charge
Meter indication of overtemperature

Battery complement: (Supplied) Two 6 volt, 8 ampere-hour sealed rechargeable batteries and one nonrechargeable 1.5 volt mercury cell. Estimated service life of the batteries is 2 years.

Battery charger: Will recharge battery in 24 hours on HIGH charging rate and maintain battery charge on LOW charging rate.

Power transfer: Chamber temperature shall not change by more than 0.003°C when transferred from line to battery operation.

Battery endurance: When fully charged, battery endurance is 2 weeks, at an ambient temperature of 20°C and 72 hours at 0°C.

AC power requirements: 115 volts ac ±10% 50 to 60 Hz at less than 15 watts or 230 volts ac ±10% 50 Hz at less than 15 watts.

Dimensions: Transvolt - 12 in W x 13 1/2 in D x 9 in H (40 cm x 34.5 cm x 23 cm).
Transit case - 16 in W x 18 in D x 11 in H (40 cm x 45.5 cm x 28 cm).

Weight: Hand carried - approximately 25 lbs (11.4 kg).
In transit case - 36 lbs (16.3 kg).

3. Installation. Using the demountable line cord supplied, plug the instrument into the appropriate power outlet with the BATT CHARGE switch in the LO position and check that the AC ON lamp on the front panel is illuminated.

a. The instrument is shipped with the batteries fully charged and generally will still be maintaining operating temperature on arrival. However, the standard cells may require 12 to 24 hours to stabilize from any mechanical disturbance due to common carrier transportation. This recovery period is considerably reduced if the unit has been hand carried. The CHARGE switch should be switched to HIGH for no more than 24 hours to bring the batteries up to full charge. The switch should then be set in the LO or trickle charge position.

b. If the unit has been in transit for an extended period of time the internal batteries may be discharged and the standard cells may not be at the correct temperature. The cells should be allowed to stabilize at operating temperature for at least 10 days before use.

4. Operation. The Transvolt Model 9145B (fig 2-13) is operated at all times from the internal battery. The AC power energizes the battery-charging circuit and the instrument should always be left connected to the ac power with the CHARGE switch in the LO position when not in transit to maintain the batteries in the fully charged condition.

CAUTION

The CHARGE switch should never be left in the HIGH position for more than 24 hours. The high charging rate does not affect the operation of the instrument but it will severely reduce battery life if left on for periods exceeding 24 hours, and excessive heating of batteries may cause the internal ambient temperature to exceed the operating temperature.

a. Front panel indicators and controls.

(1) Meter. The meter is scaled in arbitrary divisions and does not read battery voltage. It serves three indicating functions, namely:

Heater ON/OFF - meter cycles from zero to approximately three-quarter scale.

Battery state of charge - meter should indicate in the GREEN band when BATT TEST switch is depressed.

Over-temperature - meter indicates a fixed deflection at approximately half scale.

(2) BATT TEST spring-return switch is used to connect the meter to the battery to indicate the battery state of charge.

(3) AC ON lamp indicates when the unit is functioning from the ac line.

(4) BATT CHARGE switch is to enable the batteries to be recharged quickly on the HIGH position and in normal use. It is left on the LO or trickle charge position.

(5) BRIDGE ON/OFF switch energizes the temperature deviation measuring bridge.

(6) GALV terminals are for connection of an external galvanometer or detector for indicating the balanced condition of the bridge.

(7) TEMP DEVIATION control is used to null the external detector and is calibrated in terms of temperature deviation from the nominal operating temperature.

(8) CELL terminals are four pairs of highly-insulated copper terminals with low thermal EMF characteristics to which are connected the four saturated standard cells.

(9) GND terminal is connected to an electrostatic shield surrounding the cells.

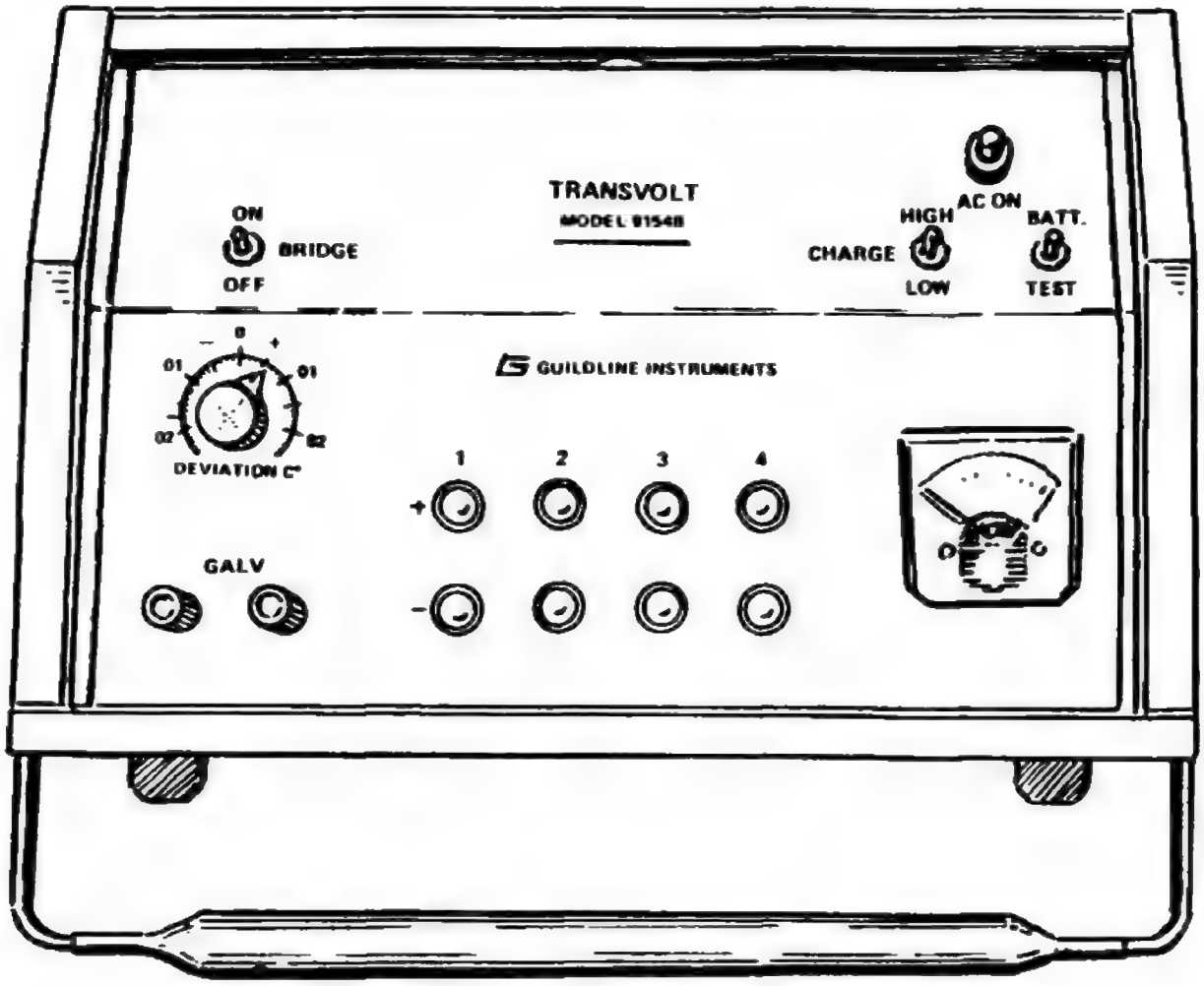


Figure 2-13. Front panel layout of Transvolt Model 9154B

b. Monitoring of internal temperature. All four arms of a Wheatstone bridge are located inside the inner enclosure. One of the arms of the bridge is a thermistor in close proximity to the standard cells; another arm of the bridge is shunted by an adjustable resistor located on the front panel of the enclosure, and calibrated over a ±0.025°C range with resolution of ±0.001°C. This bridge is not intended for the measurement of absolute temperature. It is intended only for the measurement of temperature deviation from nominal. When the cell voltages are certified, the operating temperature, as indicated by the dial is recorded, and thereafter it is necessary to know only that the cell temperature is unchanged. This is indicated by the thermistor bridge balance point.

(1) To check the cell temperature, a galvanometer is connected to the terminals marked GALV and, with the BRIDGE switch at OFF, the galvanometer is set to zero. The BRIDGE switch is switched to ON and the front panel dial

is adjusted for null deflection on the galvanometer. The temperature deviation from nominal can then be read on the dial engraving. The galvanometer should have a current sensitivity of approximately 2000 mm/μA.

(2) When an electronic detector is used instead of a galvanometer, some 60 Hz pickup may be noticed at the GALV terminals. If this pickup is excessive the detector ground terminal should be connected to the GND terminal on the back of the instrument.

(3) The BRIDGE is switched off after use to conserve life of the mercury cell.

c. State of charge indicator. The state of charge of the batteries may be checked at any time by briefly pressing down the BATT TEST spring-return switch and noting the indication on the front panel meter. When the battery is fully charged, the pointer will swing to the right end of the GREEN band on the meter. When the pointer reaches the RED band, the batteries must be recharged. When the BATT TEST switch is operated during or shortly after charging, the meter pointer will not settle at one reading but will drift slightly toward the RED band. The switch should not be held until a constant reading is obtained.

CAUTION

When the BATT test switch is depressed, a heavy current is drawn from the batteries and for this reason the test should be brief to avoid damage.

d. Overtemperature protection. An auxiliary thermostat is set to operate a few degrees above the nominal temperature. This provides protection against damage to the standard cells in the event of a failure of the temperature control system.

(1) Excessive temperature rise is prevented by closing of the thermostat which blows a fuse to disconnect the heater circuit and at the same time causes the front panel meter to indicate a fixed deflection at approximately half scale.

(2) In the event of a failure the cause should be corrected before the fuse is replaced. Failure during transit may be caused by a high ambient temperature, and the standard cell voltages should be carefully monitored for possible permanent damage.

5. Theory of operation.

a. Temperature control. The temperature control system utilizes a selected thermistor as the detection element. It is connected into a patented bistable-oscillator transistor switching system that is sensitive to changes of a few 10,000th of a degree (figs 2-14 and 2-15 at the end of the lesson).

(1) This transistor switch controls the heater current. Long-term temperature stability is guaranteed to ±0.01°C over an ambient range of 18°C to 28°C, and is provided by a system having substantially better long-term performance and sensitivity than the mercury-in-glass thermo-regulators commonly used for such applications.

(2) Changes in the internal temperature are sensed by the thermistor (R_{TH}) which is connected in series with the high-stability resistance (R_M) to form a voltage divider across the 1:2 ratio autotransformer T1. When the thermistor resistance increases (as a result of a decrease in temperature), the output from the voltage divider into the base of transistor (Q1) exceeds 50 percent of the transformer output.

(3) The circuit gain then exceeds unity, and oscillation occurs. The oscillatory signal is amplified, rectified, and activates a transistor switch, feeding current to the heater. The resulting increase in temperature decreases the thermistor resistance, and the ratio between the output voltage of the divider and the input voltage to the autotransformer falls below unity. Oscillation stops, the signal is removed from the transistor switch, and the heater current is switched off.

b. Monitoring of internal temperature. The circuit of the internal thermistor bridge is shown in the attached drawing. Two of the bridge arms are fixed manganin resistors. The third arm is a thermistor (R37) immediately adjacent to the standard cells and the fourth arm may be varied over a resistance range equivalent to a thermistor temperature change of ±0.025°C by means of the calibrated dial (R32) on the front panel and ±0.075°C by an internal trimmer (R31) which is preset at the factory and which should not require further adjustment. The bridge is powered from a small internal mercury battery (B3) and terminals are provided for the connection of an external null detecting galvanometer. The reading of the calibrated dial at balance indicated deviation (in °C, directly) of the internal temperature from nominal. Because the cells are calibrated at operating temperature inside the enclosure, it is necessary to know only that this temperature is constant and reproducible. Temperature correlation between the user's laboratory and the calibration laboratory is not necessary.

c. State of charge indication. When the BATT TEST switch (S2) is depressed, the battery is disconnected from the heater control and charging circuits and a load resistor (R22) drawing approximately one ampere is connected across the battery. At the same time the state of charge circuit is energized and the front panel meter (M1) is connected to read the difference between a zener-controlled reference voltage and a fixed fraction of the battery voltage pick off at the junction of R15 and R25.

(1) The meter acts as an expanded scale voltmeter with a range of approximately 10 to 15 volts.

(2) A trimpot (R17) is mounted on the control board to allow for variations in zener operating voltage and it is factory preset to give a meter indication at the intersection of the red and green bands when the battery voltage is 11.5 volts. The trimpot should not be readjusted.

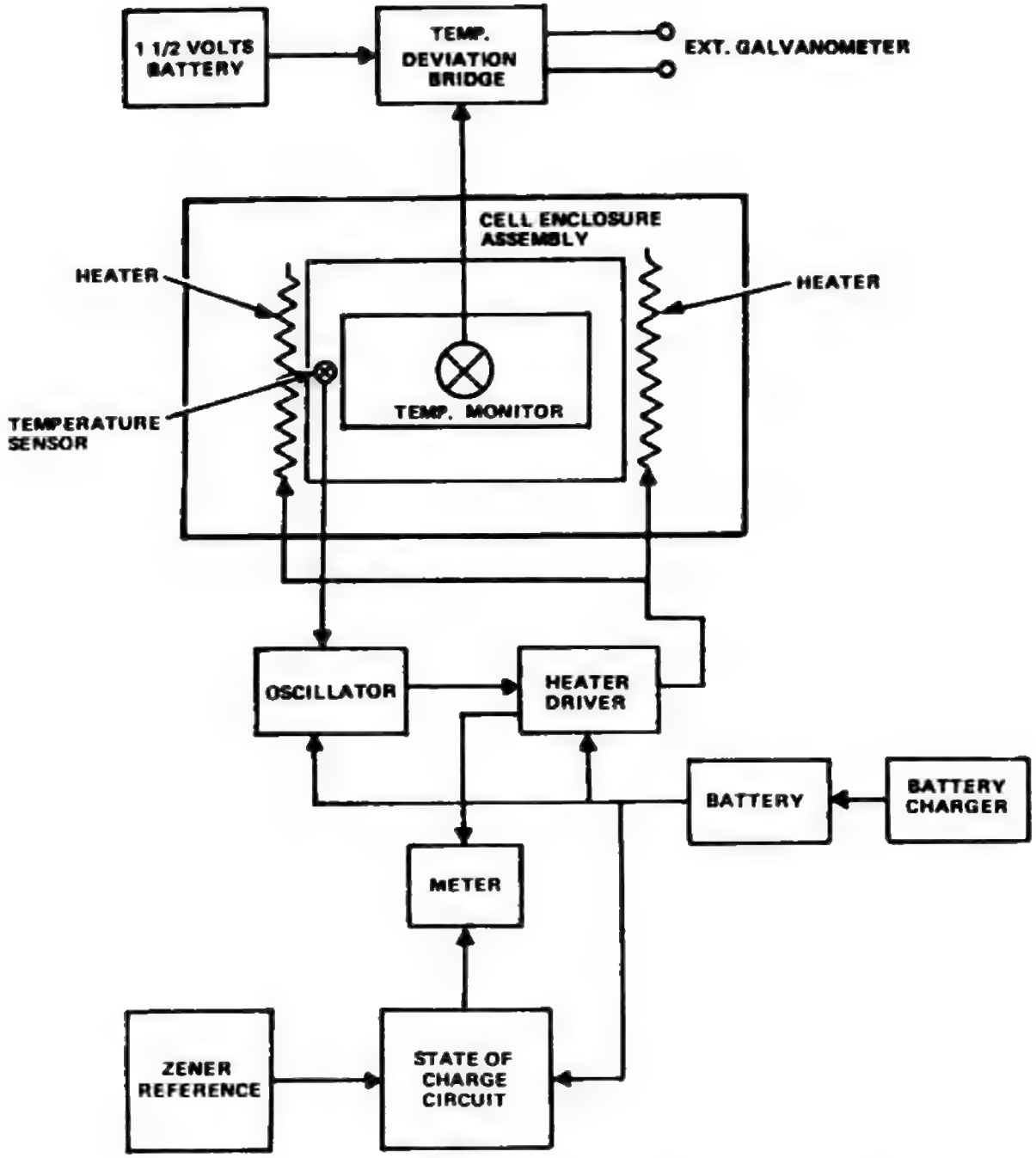


Figure 2-14. Block diagram of transvolt operation

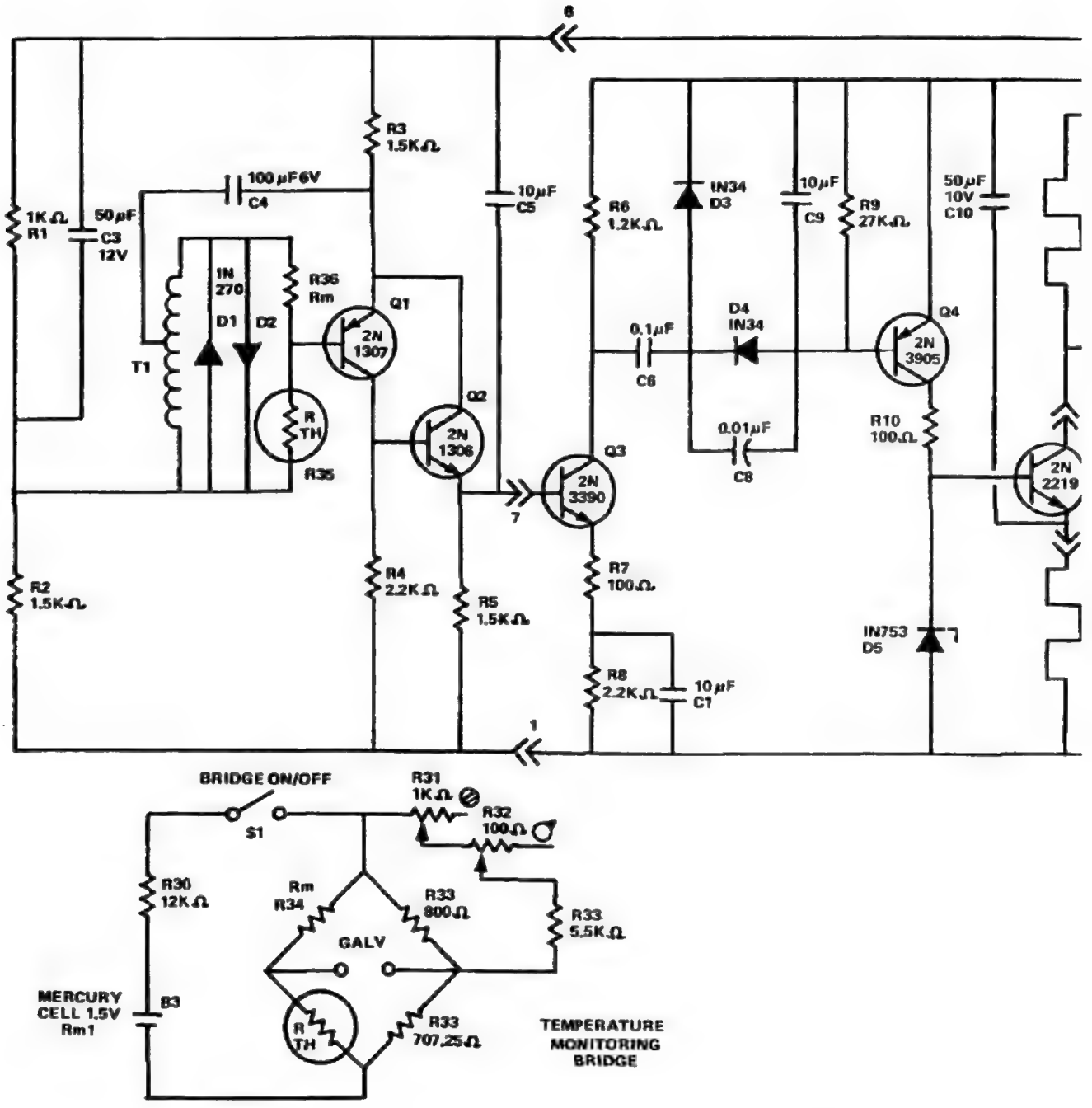
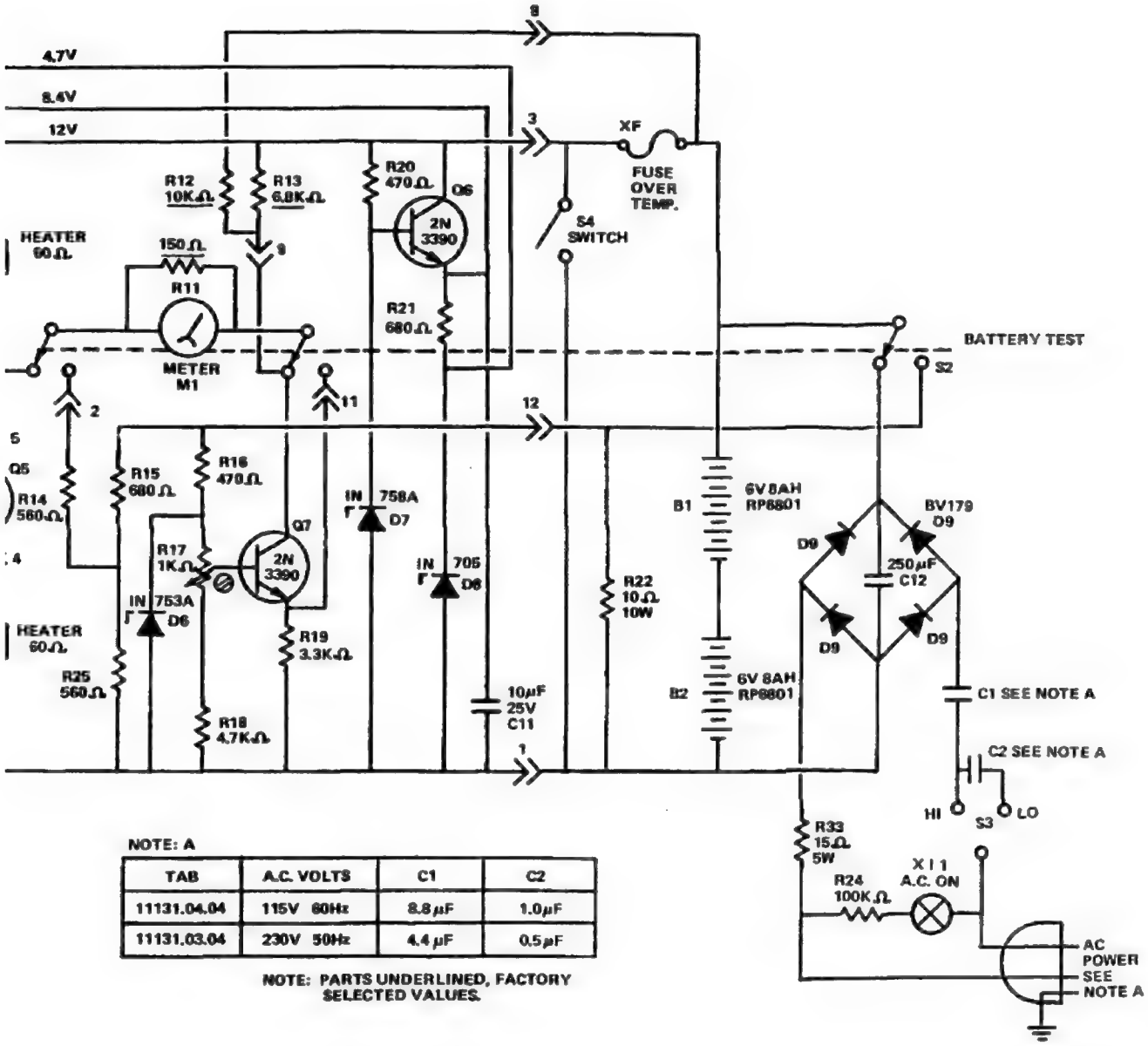


Figure 2-15 (fo). 9154B schematic diagram



NOTE: A

TAB	A.C. VOLTS	C1	C2
11131.04.04	115V 60Hz	8.8μF	1.0μF
11131.03.04	230V 50Hz	4.4μF	0.5μF

NOTE: PARTS UNDERLINED, FACTORY SELECTED VALUES.

Figure 2-15a (fo). 9154B schematic diagram

Lesson 2
PRACTICE EXERCISE

1. What is the resolution of the 9931 DC comparator potentiometer in the 0-.2 volt range?

   a. 0.1 μV
   b. 0.01 μV
   c. 0.001 μV
   d. ±(1ppm of reading + 0.02 μV)

2. What is the voltage increment per step of the $X10^{-3}$ measuring dial in the X0.1 range on the 9931 DC comparator potentiometer?

   a. 0.001 volt
   b. 0.000,01 volt
   c. 0.01 volt
   d. 0.000.1 volt

3. When measuring voltages between 0 and 0.21 volts on the 9931 DC comparator potentiometer, what should be done to achieve the greatest measurement accuracy?

   a. Rezero the 9931 with the measuring leads connected and shorted
   b. Rezero the 9931 with the measuring leads connected and open
   c. Rezero the 9931 without measuring leads
   d. Increase the gain of the 9460A Nanovolt amplifier

4. How is current stability achieved in the 9771 constant current source?

   a. By use of a high stability power supply
   b. By use of a galvanometer light beam-photo transistor amplifier combination
   c. By use of crystal-controlled oscillator
   d. By use of high impedance filter networks

5. What is the stability of the 9771 constant current source?

   a. 1ppm/12hrs + external standard cell instability
   b. 1ppm/24hrs
   c. 1ppm/24hrs + external standard cell instability
   d. 1ppm/12hrs

6. How are air bubbles removed from the galvanometer damping fluid in the 9771 constant current source after shipment?

   a. Turn the 9771 through 90° on its right side
   b. Turn the 9771 through 45° on its left side
   c. Turn the 9771 through 45° on its right side
   d. Turn the 9771 through 90° on its left side

7. Where is the lamp power cable on the 9460A nanovolt amplifier connected?

   a. To 115 volt line source
   b. 2pm connector on the left side of the 9461A galvanometer
   c. 2pm connector on the left side of the 9771 constant current source
   d. To the cells of the 9154B standard cell enclosure

8. You are using the 946DA Nanovolt Amplifier with high impedance recorder. What value of load resistor is required if the I_O is 10μA and V_O is 1mV?

   a. 100 ohm
   b. 10 ohm
   c. 1000 ohm
   d. 500 ohm

9. How should the light strips be positioned when making the final zero procedure adjustment on the 9460A Nanovolt Amplifier?

   a. Slightly offset outwards
   b. Slightly offset inwards
   c. Centered
   d Horizontal

10. How are the two photo-cells connected in the 9460A Nanovolt Amplifier?

   a. Parallel assisting
   b. Series opposing
   c. Series assisting
   d. Parallel opposing

11. What is the sensitivity of the 9461A Galvanometer?

   a. 550 ohms
   b. .002μA/mm
   c. .002mm/μA
   d. 240mm/2.5 sec

12. On what sensitivity range should the 9461A Galvanometer be mechanically zeroed?

   a. 1/1000
   b. 1/1
   c. 1/10
   d. 1.100

13. What type of cleaner should be used to clean the 9461A Galvanometer mirror?

   a. Alcohol
   b. Distilled water
   c. Chemically pure acetate
   d. Turpentine

14. What is the internal temperature of the 9154B standard cell enclosure?

    a. 35°C ± 2°C
    b. 32°C ± 0.2°C
    c. 75°F ± 2°F
    d. 32°F ± 0.2°F

15. When checking the state of charge of the batteries in the 9154B standard cell enclosure, how long should the BATT TEST switch be depressed?

    a. Momentarily
    b. Held until a constant reading is obtained
    c. 30 seconds
    d. 60 seconds

16. What is used as the detection device in the 9154B Standard Cell Enclosure temperature control system?

    a. Bistable oscillator
    b. 1:2 ratio transformer
    c. A selected thermistor
    d. Zener diode

LESSON 3
PRECISION VOLTAGE MEASUREMENT OF THE STANDARD CELL

TASK

Describe and identify theory, terminology, and procedures for precision voltage measurement of the standard cell.

CONDITIONS

Given information and illustrations about theory, terminology, and procedures for precision voltage measurement of the standard cell.

STANDARDS

Demonstrate competency of the task skills and knowledge by correctly responding to 80 percent of the multiple-choice test covering precision voltage measurement of the standard cell.

REFERENCES

National Bureau of Standards Monograph 84, January 15, 1965
TB 43-177

Learning Event 1:
DESCRIBE THE CONSTRUCTION AND MAINTENANCE OF THE STANDARD CELL

1. Voltaic cells. Since the early days of measurements, voltage references have consisted of voltaic cells of various types. The cells were, after a period of time, produced to a high degree of excellence. Techniques have been perfected so that a group of the precision type can be produced with individual differences of only a few parts per million. In addition, the cells have a long life, so they will serve satisfactorally as a standard.

2. Electromotive force (EMF). A working standard of electromotive force was recognized early as a pressing need in electrical measurements, so experimenters naturally turned to the idea of a voltaic cell to provide a reference. It was known that the EMF of a cell depended on the electrolyte and the electrode materials. Hence, there was a natural inference that a given combination of materials can be relied upon to give a definite value.

3. Cell properties. There are several properties that a cell should possess to be considered a good standard of EMF: long life, small temperature coefficient, and reproducibility. Edward Weston produced a cadmium cell in 1892 which had most of these properties. It was adopted in 1908 by the London International Electric Congress with the value of 1.0184 international volts. The international volt as a working standard was changed in 1910 to 1.0183 volts as the EMF of the Weston normal (saturated) cell at 20°C. The Weston cell has been the working (or reference) standard of EMF since that time and,

as such, has played a very important part in electrical measurements. It has fulfilled the requirements of a reference standard in a highly satisfactory way.

4. Cadmium cell. The cadmium cell is an H-shaped glass tube constructed as shown in Figure 3-1. The two legs of the cell have a rather high-temperature coefficient, but the coefficient of each leg is nearly equal in magnitude and opposite in sign. As long as the temperature of both legs is the same, it is possible to have some variation in the ambient temperature and still be within the tolerance of the cell. If there is a difference of 2.7°C between the two legs, the EMF will be changed by 1000 microvolts or 0.1 percent. Historically, the cell was enclosed in a copper-lined case to make sure that the temperature of both legs was approximately the same. Even though the copper-lined case did a good job of distributing the heat equally on both legs, it was still necessary to keep the cell out of sunlight or other radiant heat, out of drafts of cool or warm air, and away from either a warm or cool wall, because any of these conditions could cause an unequal temperature on the two legs. Modern cells are normally maintained in a temperature-controlled oven.

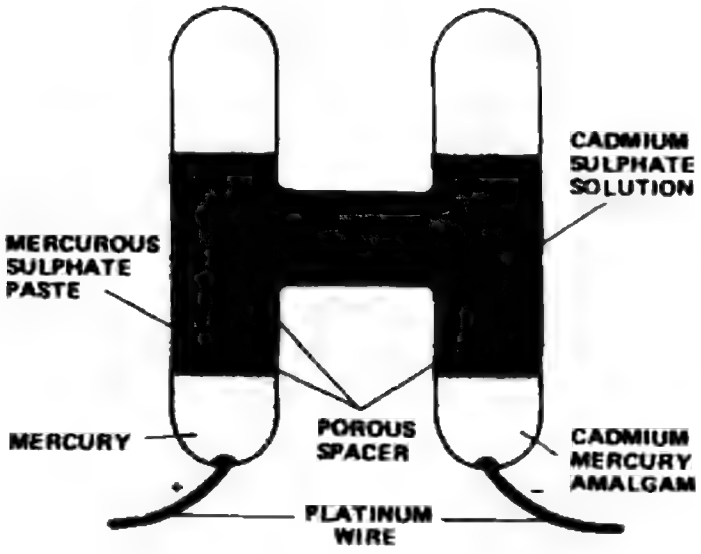


Figure 3-1. Unsaturated cell

5. Standard cells. The positive electrode is composed of mercury with dipolarized mercurous sulfate paste. The negative terminal is cadmium-mercury amalgam and the solution is cadmium sulfate (CdSO4). There are two types of standard cells, the saturated cell and the unsaturated cell. Physically, the main difference between the two is that the cadmium sulphate solution, which serves as the electrolyte, is saturated with crystals of cadmium sulphate in the saturated cell. In the unsaturated cell, the electrolyte contains no crystalline formation if the temperature is kept above 4°C.

6. Note that these electrodes can be connected to an external circuit by means of the platinum wire extensions located at the bottom of the tubes. The porous spacers which are shown in Figure 3-1 are used to separate the electrolyte and the negative electrode. Additional spacers separate the mercurous sulphate paste from the positive electrode and the electrolyte. The mercurous sulphate paste is the depolarizer for the cell. These two types of cells have different properties and different uses.

7. The saturated cell is called the "normal" cell to distinguish it from the unsaturated type and to indicate that it is the basic standard. These cells, when made of purified materials, show a high degree of uniformity. Individual cells have differences, in general, of a few microvolts from the average of a group, although an occasional cell may be much further out of line. The EMF changes somewhat during the first few years, and then settles to a comparatively steady value. These cells have the properties of reproducibility and permanence to a quite satisfactory degree.

8. There is an acid form of the cell in which the electrolyte contains added sulfuric acid. This cell appears to be better with respect to uniformity and permanence. The National Physical Laboratory in England uses it as a standard, and the National Bureau of Standards in the United States has a group of cells of this type in addition to the so-called neutral type.

9. The normal cell has a rather large temperature coefficient, about -57 μV/°C at 30°C. In fact, at 30°C, it has an effect of approximately +314 μV/°C at the positive terminal and 374 μV/°C at the negative terminal, so, it is important to keep the entire cell at uniform temperature to secure as much cancellation as possible of the plus and minus effects. These cells are always used with close temperature regulation, usually in an oil or air bath held constant to better than 0.01°C. Close regulation is needed; first because of the large temperature coefficient and second, because this type of cell is used only where high precision is required. Normal cells accommodate themselves slowly to changes in temperature and show hystersis when the cell is heated or cooled. The term "hystersis" as used here represents the lag in EMF and generally erratic behavior of the cell while it is coming to equilibrium following a change of temperature. One case has been reported where cells were subjected to high temperature accidentally, and required 2 or 3 months to recover.

10. The saturated cell is a standard for the maintenance of the volt, and as such is only used in places such at the Bureau of Standards and the largest commercial and military laboratories.

11. The unsaturated cell as stated before is similar to the normal or saturated cell except that it contains no CdSO4 crystals, and the solution is so constructed that it will become saturated at 4°C. Hence, it is unsaturated at normal room temperatures. In addition, a septum or retaining member is used over each electrode to hold the material in place against ordinary motion so that the cell is portable. (After shipment, the cell should always be allowed a few days to settle.)

12. Individual cells of an unsaturated group will have slightly different values of EMF, so each cell must be measured in terms of a primary standard. The manufacturer supplies, with each cell, a certificate specifying the value of its EMF at a particular temperature. The EMF will be slightly higher than for the saturated type. New unsaturated cells ordinarily range between 1.0190 and 1.0194 absolute volts.

13. The unsaturated cells, although less constant with age than the normal cell, is still remarkably good. Records, kept at one laboratory over a period of 10 years, of a number of cells used by qualified personnel, showed an average decline of about 0.003 percent (30 μV) per year. Statistics based on the certification and recertification of many cells sent to the National Bureau of Standards over a period of years give a much higher value than the one above. However, the conditions of use are unknown, and undoubtedly range from careful use to abuse.

14. The internal resistance of a standard cell is very important. In the unsaturated cell, it is normally between 80 and 500 ohms. If the internal resistance increases, the electromotive force decreases when current is being drawn. In most instances, the internal resistance increases as the cell becomes older.

15. There are several factors to be considered when you are using or checking a standard cell. One of the most important of these factors is the current drain which the load may cause. Since the current drain caused by an ordinary voltmeter is detrimental to the cell, such an item should never be used to determine the terminal voltage of a cell. If a cell is short-circuited, its original equilibrium is permanently upset, because cadmium is transferred from the amalgam to the electrolyte. If such a transfer occurs, the cell cannot be depended upon for accurate measurements. Current up to 100 microamperes may be drawn from the cell for short periods without permanently affecting the cell. Keep in mind that the current drawn from the cell should be as small as possible, should be drawn for the shortest period possible, and should never exceed 100 microamperes.

16. Excessive current drain (extending to accidental short-circuiting) is the most common cause of deterioration of cells. When a cell is nearing the end of its useful Life, the voltage will become increasingly unsteady. A cell's life depends, in addition to age, on the kind of treatment the cell has received, so extreme caution should be exercised when using standard cells. Also, the cells should be mounted so they are not exposed to extremes in temperature, drafts, or direct sunlight.

Learning Event 2:
DESCRIBE THE STANDARD CELL OPPOSITION MEASUREMENT TECHNIQUE

1. You have learned that the standard cell is a very important standard in the Army calibration system. Not only is it a highly accurate DC voltage standard used for calibration of other voltage standards, but it also provides a link in the chain of traceability from the National Bureau of Standards to

Army Calibration Laboratories (ACL). Thus, all DC voltage measurements maintain traceability through standard cells.

2. However, the standard cell is not an indestructible item that will not change its value over a period of time. Therefore, periodic calibration must be performed as with any other standard. Also, since the standard cell is only calibrated every 360 days, we must make measurements between calibrations to ensure that the cell's EMF value remains as given on the calibration certificate. You, as an ACL technician, may be called upon to check or even calibrate a standard cell. The measurements called for would be made using the opposition measurement technique.

3. In this technique, two standard cells, (one being the standard and the other being the test instrument), are compared against each other and only the difference EMF is measured. A standard cell group of four cells will be sent to the ACL as a reference standard. Your own cell group, being the test instrument, is compared against this transportable reference group. When making the actual measurement, certain rules must be followed to the letter. For example, the positive terminal of the left cell will always be connected to the positive terminal of the measurement system, while the positive terminal of the right cell is connected to the negative terminal of the measurement system as shown in Figure 3-2. The two negative terminals will be connected together; thus, the measurement will only measure the difference between the two cells.

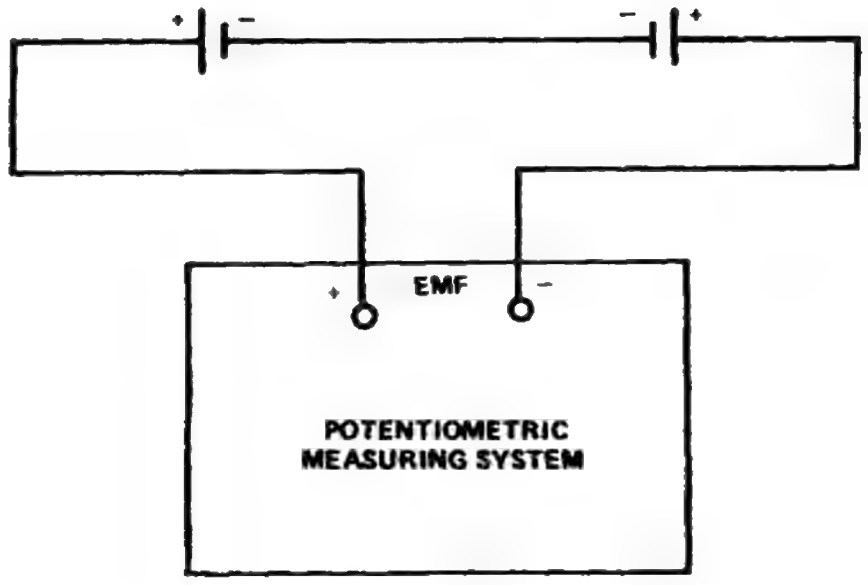


Figure 3-2. Opposition measurement connection

4. Giving one cell a value of 1.018122 and the other cell a value of 1.018116 volts, you can see that the measuring system will measure 6 microvolts. Whether this reading would be positive or negative would be dependent upon the position of the cells. If the left cell is higher in amplitude the

readout will be positive. Should the left cell have the lower amplitude, the resulting EMF will be negative. Under perfect conditions, both readings should be equal in amplitude, except the one would be a positive 6 microvolts and the other would be a negative 6 microvolts. However, as you will find, the two readings will seldom be equal in amplitude. The difference in readings is due to residual voltages present in the measurement system. This residual will either add or subtract from the measurement. Thus, you can see that by changing the cells' positions, we can detect this error introduced by the measurement system which would not be apparent if only one measurement was made. Although the manufacturer may have taken special care in the design of the measuring system, it is impossible to completely eliminate residuals. By the use of the series opposition measurement technique we can, however, detect and compensate for these residuals in the processing of the data obtained from the measurements.

Learning Event 3:
DESCRIBE THE US ARMY VOLT PROGRAM

1. Figure 3-3 indicates an ideal flow of the volt within the calibration system. It indicates an ideal traceability chain from the "Legal Volt" at the National Bureau of Standards (NBS) to the lowest level of the Army Calibration System.

2. Before continuing with our discussion of the Army Volt Program, the following terms should be understood.

a. Transport standard. A group of standard cells used to compare the unit of voltage maintained at one location to that maintained at another location. A transport standard can either be used to calibrate a reference standard or to disseminate the volt from the reference standard to other lower level standards.

b. Reference group. A designated group of cells used only for maintaining the volt in a calibration facility. This group is not normally used in performing routine calibrations.

c. Working group. A designated group of cells which may be used as a standard for performing routine calibrations in a calibration facility.

d. Observation. A noted occurrence involving a measurement with a standard or test system. An observation is the simplest piece of information (data) that has independent significance in a calibration.

e. Run. A sequential group of observations in a test procedure or measurement design.

f. Army Calibration Facility (ACF). An Army activity that is assigned the mission to provide US Army Area or Internal Calibration Laboratory Calibration and Repair Service.

3. As Figure 3-3 indicates, the US Army Volt is linked to the US Legal Volt at the NBS with procedures of the NBS Volt Transfer Program and transportable standard cell enclosures. The ACF Volt is linked to the US Army Volt at the Army Primary Standards Laboratory (APSL) with procedures of Technical Bulletin 43-177 (TB 43-177), and discussed later in this lesson, and transportable standard cell enclosures supplied and controlled by the APSL. Local surveillance of cells in the reference and working groups at the ACF will also be performed in accordance with procedures of TB 43-177.

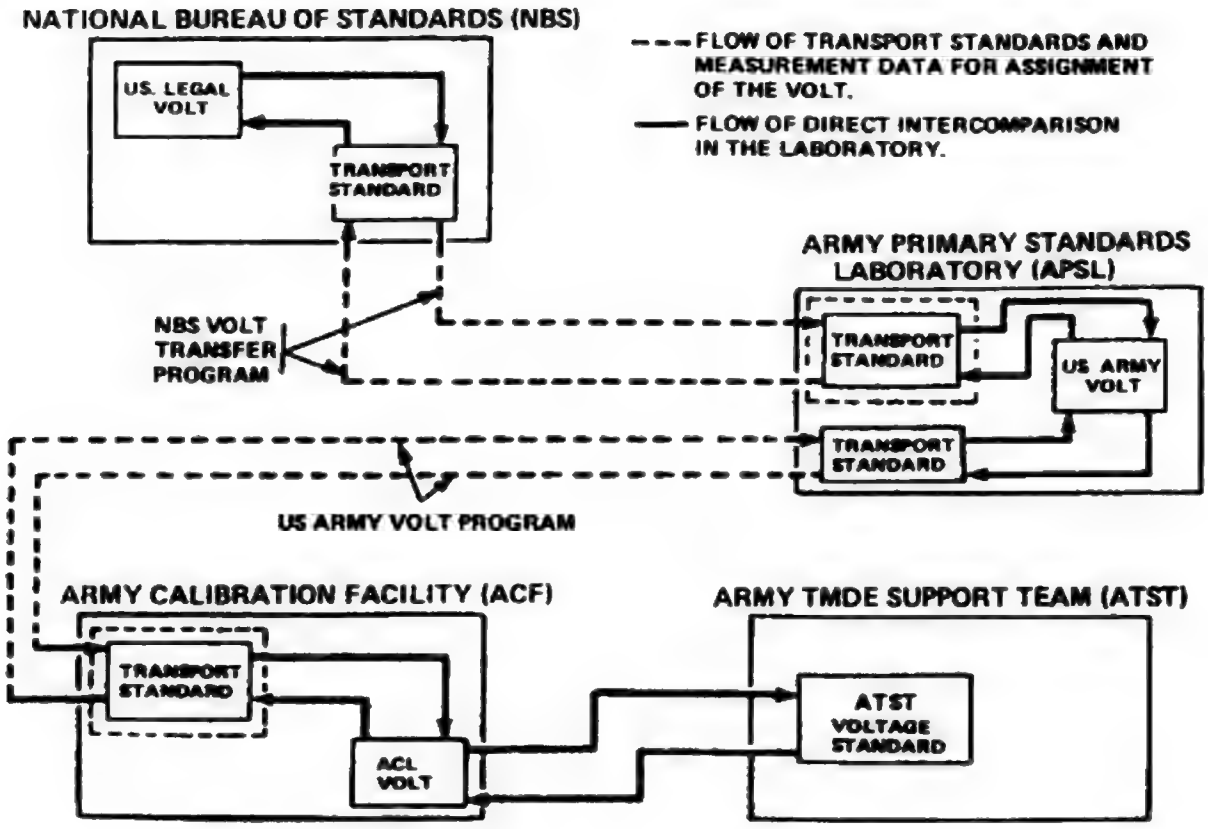

NATIONAL BUREAU OF STANDARDS (NBS)
US. LEGAL VOLT
TRANSPORT STANDARD
FLOW OF TRANSPORT STANDARDS AND MEASUREMENT DATA FOR ASSIGNMENT OF THE VOLT.
FLOW OF DIRECT INTERCOMPARISON IN THE LABORATORY.
ARMY PRIMARY STANDARDS LABORATORY (APSL)
NBS VOLT TRANSFER PROGRAM
TRANSPORT STANDARD
US ARMY VOLT
TRANSPORT STANDARD
US ARMY VOLT PROGRAM
ARMY CALIBRATION FACILITY (ACF)
ARMY TMDE SUPPORT TEAM (ATST)
TRANSPORT STANDARD
ACL VOLT
ATST VOLTAGE STANDARD

Figure 3-3. Flow chart for the US Army Volt

a. The US APSL will schedule, disseminate, and assign the values to the ACF voltage standards.

b. The ACFs, using saturated standard cells, will obtain and transmit the data as required to implement the program.

4. To implement the procedure for the calibration of cells at the ACF, the program schedules, methods of shipping the transport standards, observation forms, and data transmission instructions will be controlled by the APSL to assure calibration of the ACF standard cell as required by TB 43-180. Program intervals may be shortened or extended by the APSL to satisfy emergency needs or to meet individual requirements.

a. Upon receipt of the transport standard at the ACF, it shall be inspected while on battery power to ascertain that it is maintaining operating temperature (periodic cycling of front panel meter). If front panel meter does not cycle, contact the APSL for guidance. If periodic cycling is evident, the transport standard shall then be connected to a 115-V ac line power in the laboratory environment area in which measurements are to be made. The batteries of the transport standard shall be checked and recharged as necessary to bring them to a full-charge condition. The battery charge switch should be placed in the "Lo-Charge" position during normal operation.

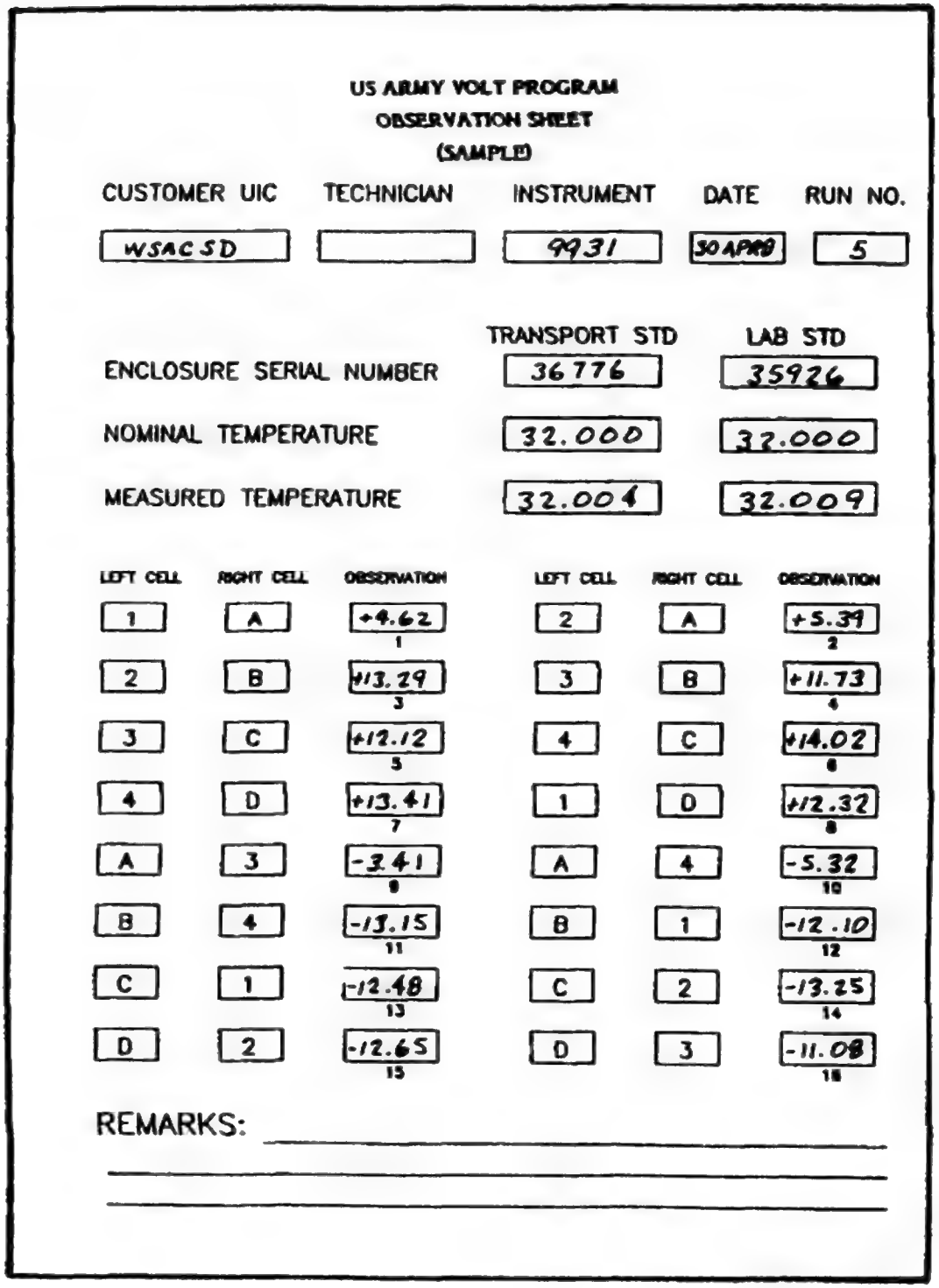
b. The transport standard shall be allowed to stabilize in the laboratory environment for at least 24 hours before observations are begun. The first set of observations will then be made using a typical format for a 4-cell by 4-cell comparison which consists of 16 observations taken in the order specified in the observation sheet (fig 3-4). A series of 8 observations will be taken with cells connected as in Figure 3-5, and a series of 8 observations will be taken with cells connected as in Figure 3-6. For clarity and to eliminate confusion in the measurement process, the transport standard cells are designated 1 through 4 and the laboratory standards A through D. The first set of observations shall be transmitted to the APSL immediately for analysis to determine a go or no-go condition for the transport loop.

(1) A go-condition will be assumed by the ACF and intercomparisons shall continue at a rate of not less than two per week until notification by the APSL.

(2) If a no-go condition exists, the APSL will advise the ACF to discontinue the observations and will provide further instructions as necessary.

(3) Data sheets will be mailed directly to the APSL.

c. Upon completion of the observations at the ACF and return of the transport standard to the APSL, the cell values shall be redetermined with respect to the US Army Volt. If this redetermination and the ACF intercomparison data are conclusive, a test report and DA Label 80 will be completed and transmitted to the ACF calibrating the enclosure(s).



US ARMY VOLT PROGRAM
OBSERVATION SHEET
(SAMPLE)

CUSTOMER UIC	TECHNICIAN	INSTRUMENT	DATE	RUN NO.
WSACSD		9931	30APR8	5

	TRANSPORT STD	LAB STD
ENCLOSURE SERIAL NUMBER	36776	35926
NOMINAL TEMPERATURE	32.000	32.000
MEASURED TEMPERATURE	32.004	32.009

LEFT CELL	RIGHT CELL	OBSERVATION		LEFT CELL	RIGHT CELL	OBSERVATION	
1	A	+4.62	1	2	A	+5.39	2
2	B	+13.29	3	3	B	+11.73	4
3	C	+12.12	5	4	C	+14.02	6
4	D	+13.41	7	1	D	+12.32	8
A	3	-3.41	9	A	4	-5.32	10
B	4	-13.15	11	B	1	-12.10	12
C	1	-12.48	13	C	2	-13.25	14
D	2	-12.65	15	D	3	-11.08	16

REMARKS: _____

Figure 3-4. Sample observation sheet completed

d. If upon return of the transport standard to the APSL, either the cell value redetermination or the observation data are found to be inconclusive, a rescheduling for calibration will be made and the procedure repeated.

5. Surveillance of the reference and working groups of cells will be maintained. Surveillance will consist of monthly comparisons of the reference and working cells and plotting the computed value of each cell and the mean of the groups.

a. The following computations and graphs are required:

(1) The value of each cell and the mean of the working group based on the mean of the reference group (compute and graph).

(2) The value of each cell in the reference group based on the mean of the reference group (compute and graph).

(3) Left-right component (compute only).

b. Upon receipt of the calibration report from the APSL, the ACF will construct graphs similar to Figure 3-7 and should be in accordance with 1 through 3 below:

(1) Enter the calibration report value for each of the cells and the mean of each group at the appropriate point on the graphs at time zero and enter the date at the bottom of the graph.

(2) Enter the upper and lower control limits. These limits will be supplied by the APSL in the calibration report.

(3) At monthly intervals following calibration, compare the reference and working cells and compute the value of all cells in terms of the mean of the reference group. Enter the computed data in the graphs.

c. Surveillance plots are considered within control if plotted data is within upper and lower control limits.

d. Out-of-control conditions and actions will be determined in the following manner:

(1) The average left-right component (residual EMF) is 0.10 μV for systems used in the ACFs. Any computed left-right component exceeding 0.30 μV indicates a requirement for determining system errors (sources of thermal EMF, cell instability, potentiometer errors, etc.). In situations where left-right component computations exceed 0.30 μV and the sources of errors cannot be traced locally, guidance should be requested from the APSL.

(2) Control limits on the surveillance charts signal out-of-control conditions for the cell. Individual out-of-control cells in the working group should not be used as standards for calibration; however, surveillance should continue. In some cases, the condition will be temporary and will return to an in-control condition. In the event of an out-of-control working group mean, request guidance from the APSL. The reference group mean will track a straight line by definition. In the event as many as two reference group cells drift out-of-control, request guidance from the APSL.

Learning Event 4:
DESCRIBE MEASUREMENTS FOR CALIBRATION OF STANDARD CELL ENCLOSURES AT ARMY CALIBRATION FACILITIES

1. In the preceding learning event, the US Army Volt program was described. In this learning event the measurement procedures for the calibration and surveillance of standard cell enclosures will be described. The data that is collected from these measurements is computed using a set of formulas that will determine the validity of the surveillance and calibration, however, the actual computation of these formulas is beyond the scope of this subcourse and will not be covered. They will be covered in the Army Calibration Laboratory Procedures subcourse. This subcourse is only concerned with the measurement procedure required to obtain the data to be used with the formulas.

2. When performing the standard cell measurements the ACF will complete one US Army Volt Program observation sheet (fig 3-4) for each run according to the following instructions:

a. Customer UIC. Enter the six-character unit identification code assigned to your calibration facility.

b. Technician. Enter the last name of the technician performing the measurements.

c. Instrument. Enter the model number of the instrument used to obtain the measurements.

d. Date. Enter the date the measurements were made.

e. Run number. Enter the number of the run. (The first set of data on a cell enclosure is run number 1, the second is run number 2, etc.)

f. Enclosure serial number. Enter the serial numbers for the transport standard and the lab standard in the appropriate column.

g. Nominal temperature. Enter the nominal temperature of each enclosure in the appropriate column. (The nominal temperature is the "set-temperature" of the enclosure and is usually stamped near the temperature dial or on the nameplate of the enclosure.) Guildline, Model 9154B enclosures, have a nominal temperature of 32°C.

h. Measured temperature. Enter the measured temperature of each enclosure in the appropriate column. (Temperatures should be measured to the nearest .001°C. It is important that this data be entered in the proper blocks.)

i. Observations. Enter the observed readings in microvolts. (Resolution should be at least 0.1 μV. Example, 12.3 μV.)

j. Remarks. Remarks are optional but give the technician a place to record any conditions that might have affected the data. (Example: heavy traffic in measurement area, changing environment, etc.)

3. Caution should be exercised when connecting and disconnecting cells. Handling of wires and connectors should be minimized to keep thermal EMFs as low as possible. When observations begin, there should not be extended delays in completing the total observation series. Observations must be made in the order specified by the numbers under the observation blocks on the observation sheet. This conserves the trend-eliminating feature of the measurement design.

4. The equipment is connected as shown in Figure 3-5 and measure the difference between cell 1 of the transport standard and cell A of the lab standard is measured. The observed value, with proper sign, is entered in observation block number 1 (this is the value of cell 1 - (minus) cell A).

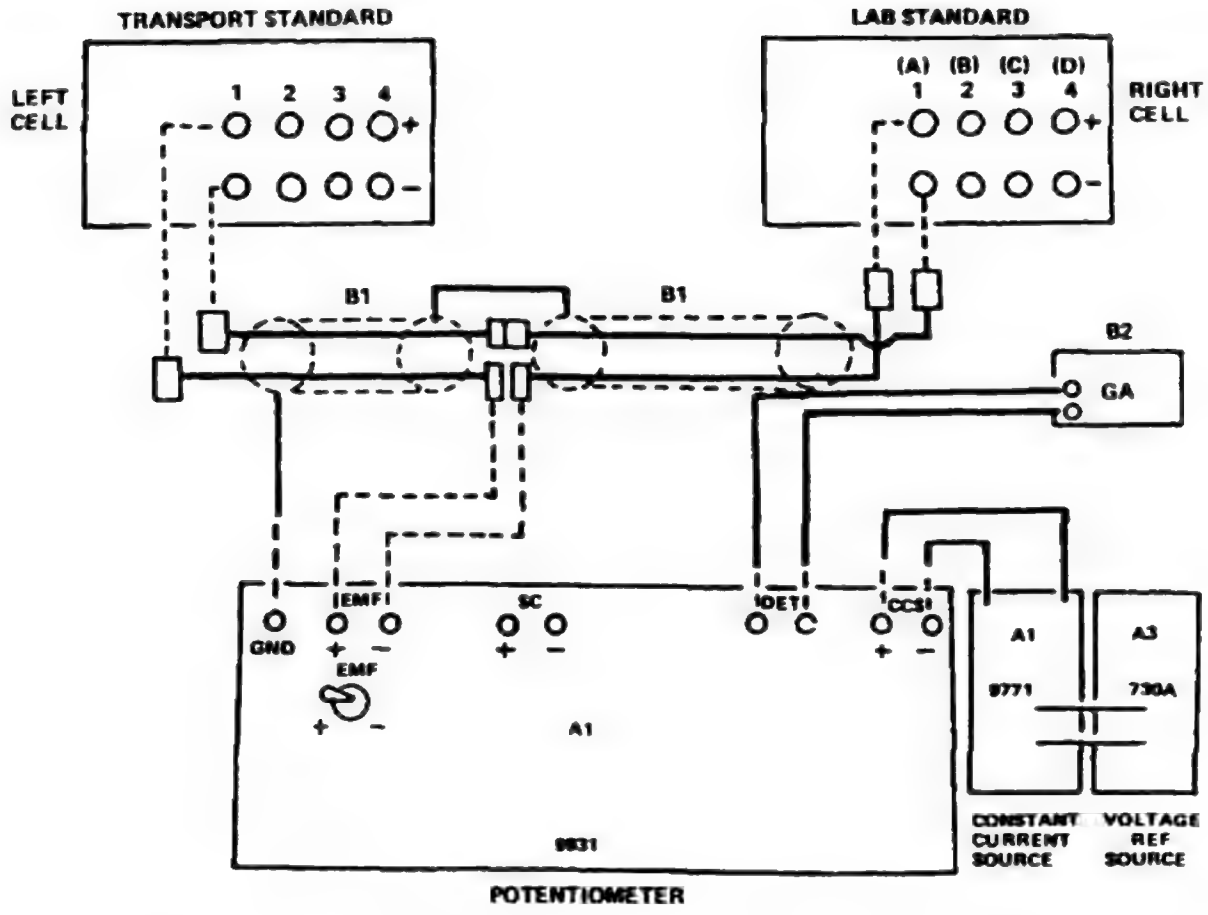


Figure 3-5. Equipment setup for normal observations

5. Leads from cell 1 are moved to cell 2 of the transport standard and the difference between cell 2 of the transport standard and cell A of the LAB standard is measured. Enter the observed value, with proper sign, is entered in observation block number 2 (this is the value of cell 2 - (minus) cell A).

6. Leads from cell A are moved to cell B of lab standard and measure the difference between cell 2 of the transport of the transport standard and cell B of the lab standard is measured. The observed value, with proper sign, is entered in observation block number 3 on the second line (this is the value of cell 2 - (minus) cell B).

7. The leads are alternately moved and make the measurements are made as required to obtain observations four through eight to complete the remaining five observations of this series.

8. The equipment is connected as shown in Figure 3-6 and measure the difference between cell A of lab standard and cell 3 of transport standard is measured. The observed value, with proper sign, is entered in observation block number 9 of the next line (this is the value of cell A - (minus) cell 3). Note that the positive EMF lead of the potentiometer is now connected to the lab standard and the negative lead to the transport standard.

9. The leads are alternately moved and the measurements are made as required to obtain observations numbered 10 through 16 to complete the remaining seven measurements of this series.

NOTE

The position of the potentiometer EMF-REVERSAL switch is governed by the actual difference between the cell EMFs. When the switch is in the "+" position the sign for the observation is positive (+), and when in the "-" position, the sign is negative (-). Figures 3-5 and 3-6 reflect typical switch observations for observations when the temperature of the transport standard is significantly lower than that of the lab standard.

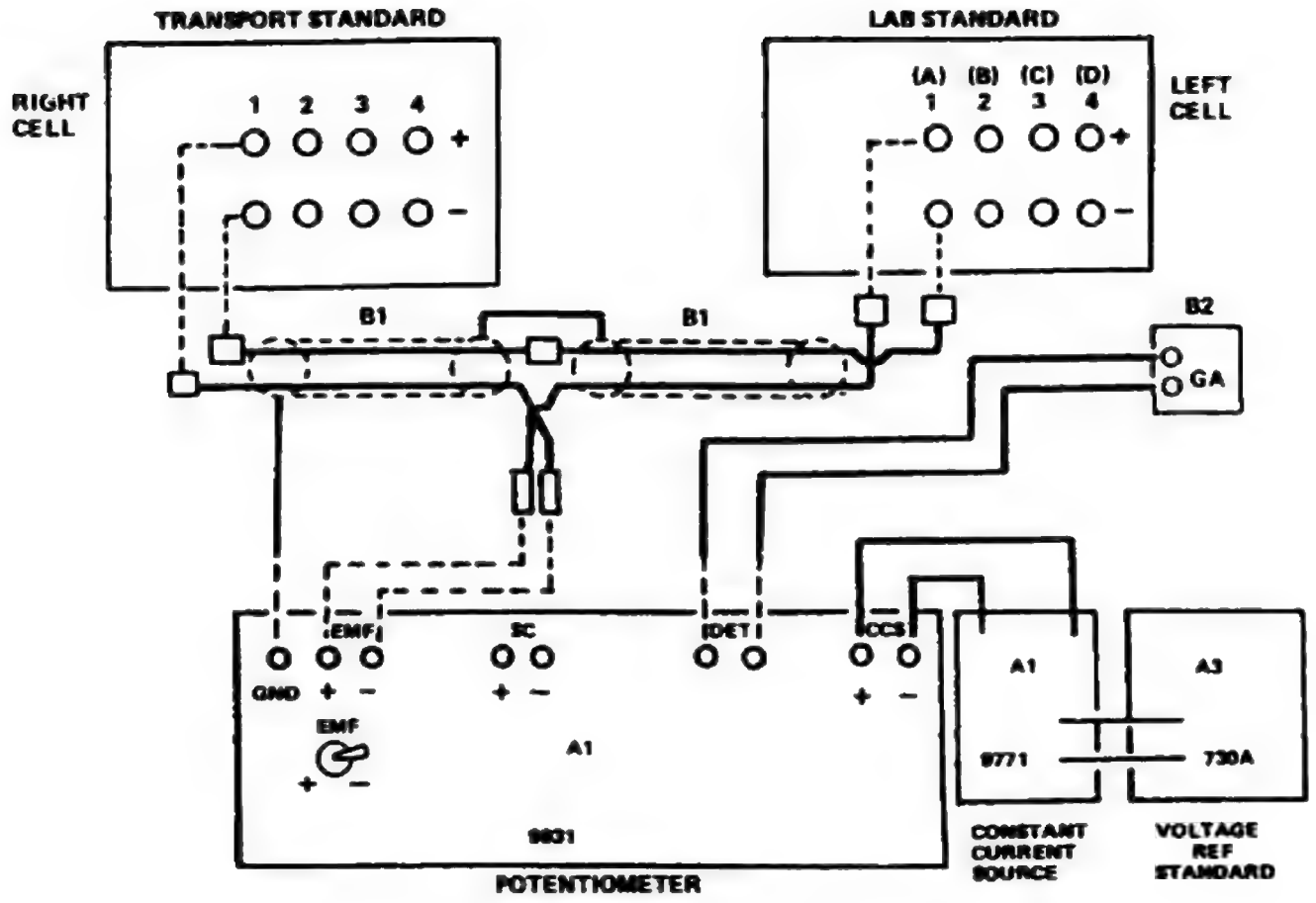


Figure 3-6. Equipment setup for reverse observations

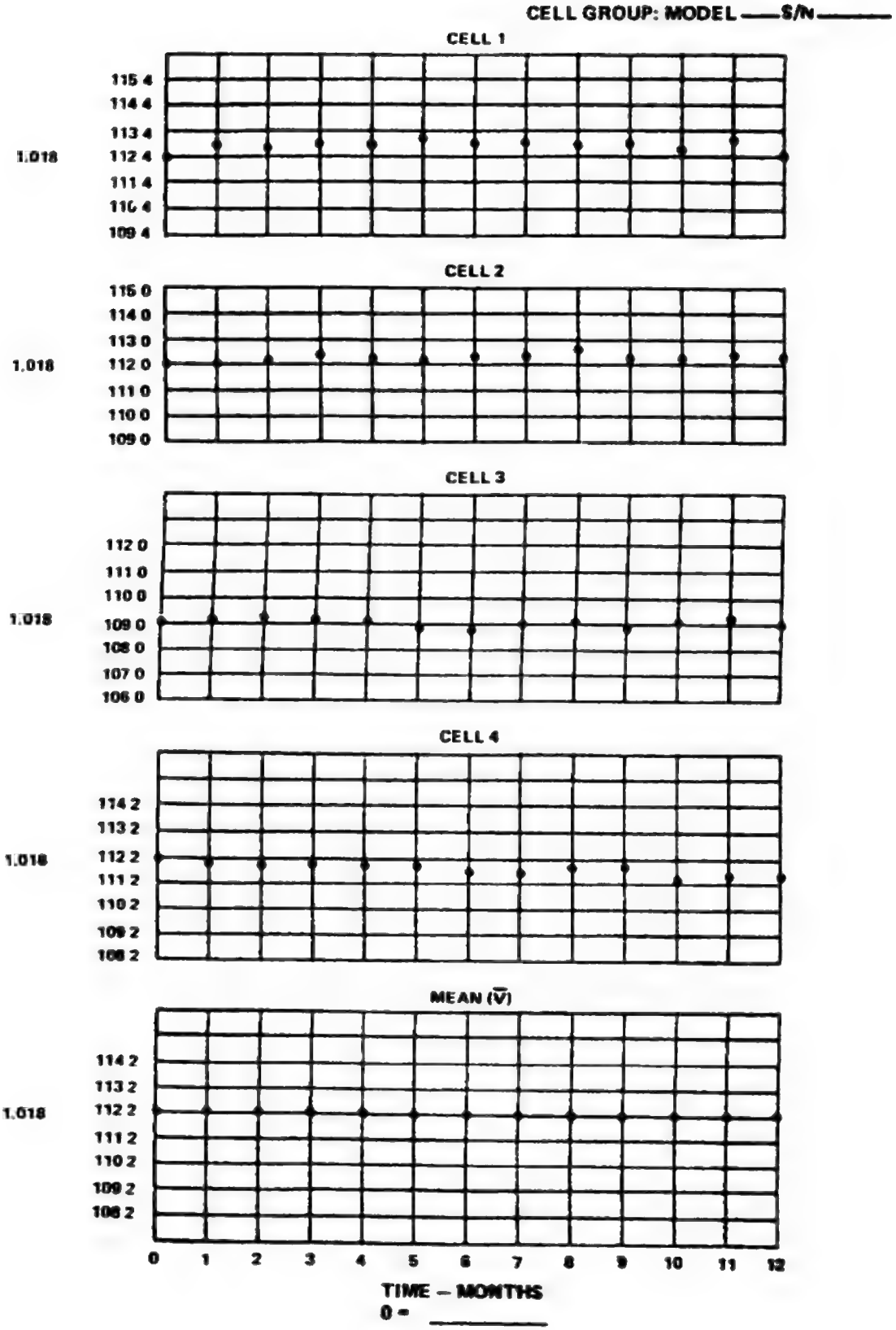


Figure 3-7. Standard cell graphs

Lesson 3
PRACTICE EXERCISE

1. What is the EMF of an standard cell dependent upon?

   a. Electrolyte
   b. Electrode materials
   c. Shape of cell housing
   d. Electrolyte and electrode materials

2. What are the two types of standard cells?

   a. Voltaic and saturated cell
   b. Voltaic and unsaturated cell
   c. Saturated and unsaturated cell
   d. Alkaline and mercury cell

3. What is the absolute voltage range on new unsaturated cells?

   a. 1.0190 to 1.0194
   b. 1.0183 to 1.0184
   c. 1.0910 to 1.0914
   d. 1.0813 to 1.0814

4. When connecting standard cells to the measuring system using the opposition measurement technique, what rule should be followed?

   a. The negative terminals of the stand cells should be connected together
   b. The negative terminals of the standard cells should be connected to the negative terminal of the measuring system
   c. The positive terminals of the standard cells should be connected to the positive terminals of the measuring system
   d. Both b and c above

5. You are measuring two standard cells using the opposition measurement technique. If the left cell is 1.018117 and the right cell is 1.018122, what voltage will be measured?

   a. +5 microvolts
   b. -5 microvolts
   c. +9 microvolts
   d. -9 microvolts

6. What is the name of a group of cells used ONLY for maintaining the volt in a calibration facility?

   a. Working group
   b. Calibration group
   c. Reference group
   d. Transport standard

7. What is the name of a group of observations in a test procedure or measurement design?

   a. Sequence
   b. Audit
   c. Run
   d. Test data

8. How long should the transport standard be allowed to stabilize in the ACF?

   a. 24hrs
   b. 12hrs
   c. 6hrs
   d. 16hrs

9. How many observations are taken in a four-cell by four-cell comparison?

   a. 8
   b. 16
   c. 32
   d. 4

10. Which cells of the transport and lab standard are compared in observation 2?

    a. 2 and B
    b. 2 and A
    c. 1 and B
    d. 1 and A

LESSON 4
NULL DETECTOR 845R

TASK

Describe and identify theory, terminology, operation, and troubleshoot Null Detector 845AR.

CONDITIONS

Given information and illustrations about theory, terminology, operation, and troubleshooting of Null Detector 845AR.

STANDARDS

Demonstrate competency of the task skills and knowledge by correctly responding to 80 percent of the multiple-choice test covering Null Detector 845AR.

REFERENCES

Technical Manual for Fluke Model 845AR Null Detector

Learning Event 1:
DESCRIBE THE 845AR NULL DETECTOR

1. The Fluke Model 845AR High Impedance Voltmeter-Null Detector allows measurement of dc voltages from 1 microvolt to 1000 volts dc in 19 ranges. When used as a null detector on the 100-millivolt range and below, the input impedance is an excellent 10 megohms. A linear recorder output allows the instrument to be used for production testing, and also a dc amplifier with a maximum gain of 120 db.

2. The instrument may be wired to operate from a line power source of 115 volts ac or 230 volts ac, as desired. The instrument is designed to be mounted directly in a standard ETA 19-inch relay rack. Resilient feet are also provided for bench top use.

3. Electrical specifications.

a. Input voltage range. 1 microvolt to 1000 volts dc end scale in 19 ranges, using X1 and X3 progression.

b. Input resistance. 100 megohms on 300 millivolt range and above; 10 megohms on 100-millivolt range and below.

c. Accuracy. ±(3% end scale + 0.1 microvolt).

d. Maximum noise (input shorted).

Range	Noise (peak-peak)
1 microvolt	0.20 microvolt
3 microvolt	0.25 microvolt
10 microvolt - 1000 volt	0.30 microvolt

e. Meter response time (to 90% of reading).

Range	Time
1 microvolt	5 seconds
3 microvolt	3 seconds
10 microvolt - 1000 volt	1 1/2 seconds

f. Input isolation. Better than 10^{12} ohms at less than 50% relative humidity and 25°C regardless of line, chassis, or recorder grounding. Better than 10^{10} ohms up to 80% relative humidity and 35°C. With driven guard, isolation improves by at least one order of magnitude up to 10^{13} ohms. Any input terminal may be floated 1100 volts off chassis ground.

g. DC common mode rejection. Better than 160 db, input short-circuited, 80% relative humidity; better than 140 db, open-circuited, 50% relative humidity; better than 120 db, open-circuited, 80% relative humidity.

h. AC common mode rejection (below 100 kHz). 100 volts RMS or 120 db greater than end scale, whichever is less, will affect reading less than 2% of end scale. Input open-circuited.

i. AC normal mode rejection (60 HZ and above). AC voltages 60 db above end scale will affect reading less than 2% of end scale. Maximum voltage not to exceed 750 volts RMS.

j. Recorder output. 0-1 volt, one side at chassis ground; linear to 0.5% of end scale. Source impedance, 5k to 7.5k.

k. Stability of zero. Better than 0.15 microvolt/hr, better than 0.3 microvolt/day.

l. Temperature coefficient of zero. Less than 0.1 microvolt°/C from 15°C to 35°C. Less than 0.2 microvolt/°C from 0°C to 50°C.

m. Zero control range. ±5 microvolt minimum.

n. Overload protection. Up to 1100 volts dc may be applied on any range. Typical recovery time is 4 seconds.

o. Input power. 115/230 volts ac ±10%, 50 to 440 Hz; approximately 3 watts.

p. Operating temperature range. Within all specifications from 15°C to 35°C. Within all specifications from 0° to 50°C except:

Derate by a factor of two -
Maximum Noise and Meter Response Time.
DC Common Mode Rejection -
Derate by 20 db.

q. Storage temperature range. -40°C to +70°C.

r. Relative humidity range. 0 to 80%.

s. Weight. 9 pounds.

t. Size. 3.47 in high x 19 in wide x 8.26 in deep.

Learning Event 2:
DESCRIBE OPERATION OF THE 845AR NULL DETECTOR

1. All operating controls, indicators, and terminals are mounted on the front panel of the 845AR Null Detector as shown in Figure 4-1, and have the following functions as described a through g.

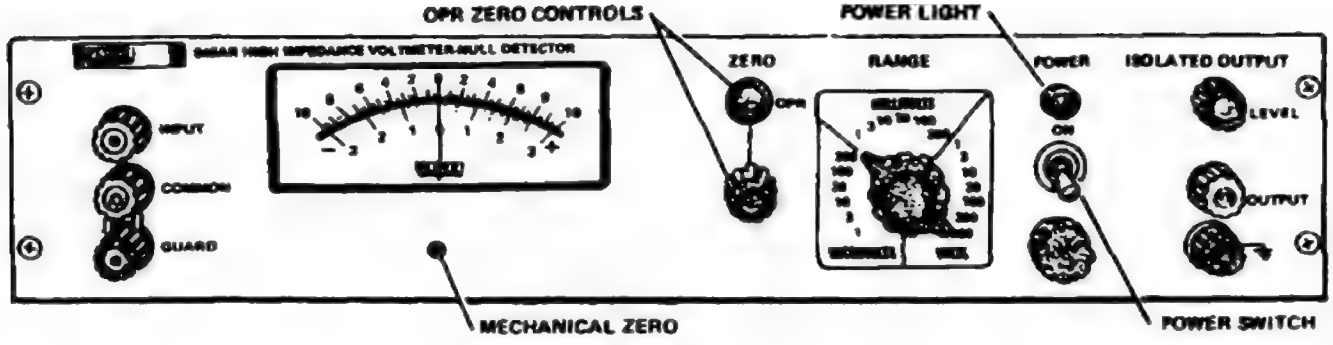


Figure 4-1. Model 845AR High Impedance Voltmeter-Null Detector

a. Meter. Indicates the voltage applied to the input terminals.

b. Input and common terminals. Provide connection to voltage being measured.

c. Guard terminal. This terminal is usually strapped to the common terminal. The terminal is connected directly to an inner chassis shield. By removing the strap, a guard potential equal to the common terminal potential may be applied to the guard terminal, shunting the leakage current from the common terminal to ground.

d. Isolated output terminals. Provide connection to an external recorder.

e. Isolated output level control. For full-scale meter deflection, this control allows adjustment of the isolated output voltage from 0 to 1 volt dc.

f. Range control. Provides selection of the desired full-scale sensitivity.

g. OPR/ZERO controls. Zero opens input terminals and shorts amplifier input allowing zeroing of the instrument with the lower zero control. In OPR position the instrument is ready for operation as a voltmeter or null detector.

2. To electrically zero the Model 845AR, the controls would be placed in the following positions:

POWER	ON
RANGE	10 MICROVOLTS
OPR/ZERO	ZERO

The zero control is then adjusted for an initial zero meter deflection. The RANGE switch is set to the 1 MICROVOLT RANGE and then rezeroed with the zero control.

3. It may become necessary to adjust the mechanical zero control of the Model 845AR at more frequent intervals than complete calibration. To mechanically zero the instrument, the following procedure would be followed:

a. The RANGE switch is placed to 1000 VOLTS and the POWER switch to ON.

b. The mechanical zero adjustment screw is adjusted for zero meter deflection.

c. The RANGE switch is set to 10 MICROVOLTS and the instrument is electrically zeroed.

d. Steps a and b are repeated.

4. To operate the Model 845AR as a High Impedance Voltmeter, the preliminary operations according to paragraph 2 are performed and the following procedures would be followed:

a. The controls are placed as follows:

POWER	ON
OPR/ZERO	OPR
RANGE	1000 VOLTS

NOTE

When measuring voltages in the microvolt ranges, copper wire having low thermal EMFs is used.

b. The voltage to be measured is connected to the Model 845AR INPUT terminal and the common point of the voltage being measured is connected to the COMMON terminal.

c. Deflection of the meter indicates the polarity and magnitude of the measured voltage. The sensitivity of the Model 845AR is increased for maximum on-scale deflection.

5. The Model 845AR may be used to monitor small voltage differences in bridge circuits, potentiometers, and other measuring apparatus. In most of these applications the circuits are adjusted for zero deflection or a null on the Model 845AR. Equipment connections for various types of null detector configurations are illustrated by Figures 4-2 through 4-4. To operate the Model 845AR as a null detector, perform the preliminary operations according to paragraph 2 are performed and the following procedure would be followed:

a. The desired equipment application is selected as illustrated by Figures 4-2 through 4-4 and the appropriate equipment connections are made.

b. The Model 845AR controls are placed as follows:

POWER	ON
OPR/ZERO	OPR
RANGE	as desired

c. The circuit being measured is adjusted for zero or a null deflection on the Model 845AR meter.

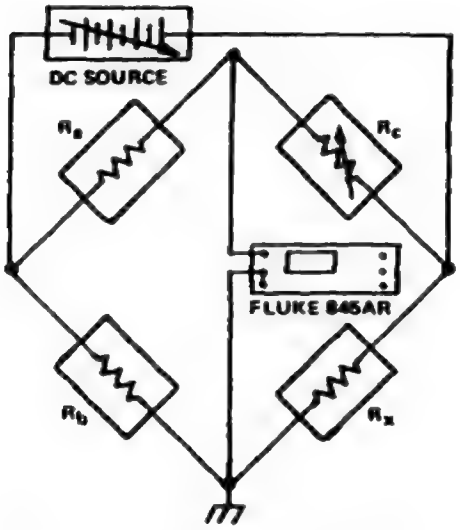


Figure 4-2. Bridge detector - floating supply

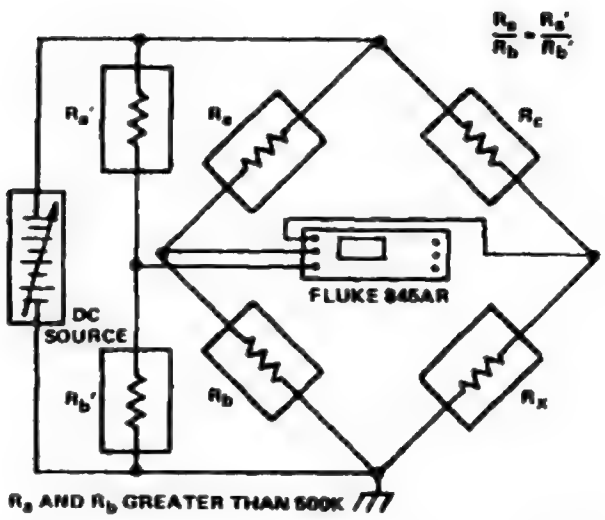


Figure 4-3. Bridge detector - high resistance

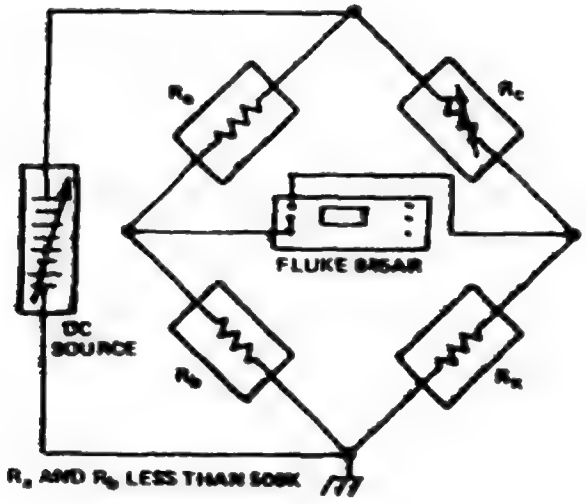


Figure 4-4. Bridge detector floating null detector

6. The Model 845AR may be used with a voltage divider and a standard cell to calculate unknown voltages with a high degree of accuracy. The equipment is connected as illustrated in Figure 4-5. The preliminary operation as outlined in paragraph 2 is performed and the following procedure would be followed:

a. The Model 845AR controls are placed as follows:

POWER	ON
OPR/ZERO	OPR
RANGE	as desired

b. The voltage divider is adjusted for zero or null deflection on the Model 845AR meter while placing the RANGE switch to successively more sensitive ranges.

c. The unknown voltage is calculated by dividing the standard cell voltage by the final division ratio of the divider.

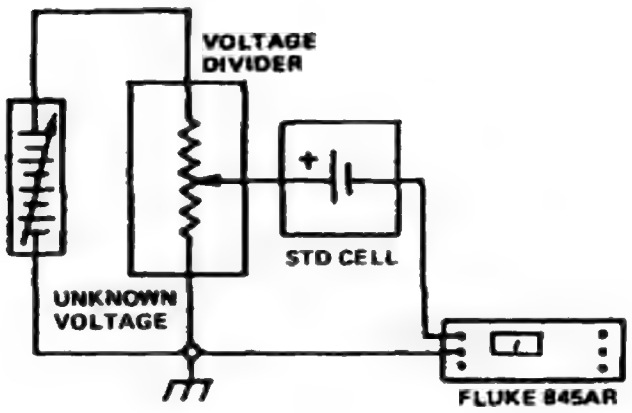


Figure 4-5. Standard cell voltage measurements

7. The Model 845AR may be used as a dc isolation amplifier having a voltage gain of up to 120 db, depending on the settings of the RANGE switch and the OUTPUT LEVEL control. To compute the maximum voltage gain on any range of the Model 845AR, use the following formula:

$$\text{Voltage gain in db} = 20 \log_{10} \times \frac{\text{1 volt (maximum isolated output)}}{\text{Range (in volts)}}$$

8. Voltage measurements at the microvolt level involve the persistent problems of thermoelectric effects. These effects may be compensated for by temporarily disconnecting the voltage from the circuit under measurement and noting the meter deflection of the Model 845AR on the desired range. This reading must then be subtracted from all subsequent voltage measurements. A thorough understanding of these effects can lead to reducing or eliminating them completely.

9. If a circuit is composed of two dissimilar metals, a net voltage will result if the two dissimilar junctions are maintained at different temperatures. These thermoelectric voltages, also known as thermals, thermo-couple voltages, or Seebeck voltages, can be reduced by using metals having low thermoelectric potentials, and keeping all junctions at the same temperature. The terminals of the Model 845AR are made of pure copper, gold-flashed to prevent tarnish. For lowest thermal voltages, all connections to the Model 845AR should be made with pure copper wire. Silver-plated copper or solder-coated copper also produce satisfactory results. Tinned copper is less satisfactory than silver-plated or copper-coated copper. Nickel and nickel-based alloys are not suitable for connections to the instrument. Excellent results can be obtained using ordinary TV twin lead, or even lamp cord if high insulation resistance is not required. If shielding is necessary, use a length of flat braid over the cable.

10. Due to the very high input resistance and extreme sensitivity of the Model 845AR, it is charge sensitive. Thus, a person's body potential, an electrostatic voltage, can cause charge redistribution at the input to the instrument and result in meter needle deflection as a hand approaches the input terminals. Careful shielding will eliminate this problem. Also, due to charges that may be deposited on the input terminals when the OPR-ZERO switch is set to ZERO, an appreciable transient will result when the switch is set to OPR if nothing is connected to the input terminals. Turning the switch back and forth will dissipate this charge, eliminating the problem. With a high source impedances, the response of the instrument is unavoidably slow due to the low pass filter used to suppress superimposed noise. However, the design of the low pass filter is such that common mode rejection is extremely high while the response time for the normally encountered low source impedances is very fast.

11. The instrument is designed to withstand up to 1100 volts dc or 1100 volts peak ac continuously applied between any two of the three input terminals or between cabinet ground and any of the three input terminals regardless of the setting of the RANGE or OPR-ZERO switch. However, repeated or continuous overloads above 200 volts in the ranges below 3 millivolts will result in dissipation in protective, low-pass-filter resistor R110. This will result in thermal voltages which may take several minutes to subside after the overload is removed.

12. The instrument has an inner chassis connected to the GUARD terminal on the front panel. Ordinarily, this GUARD terminal is strapped to the COMMON terminal. When connected in this way the inner chassis serves as a shield. This greatly improves the leakage resistance to ground and the common mode rejection. However, since the inner chassis is available at the GUARD terminal, it may be driven at the same voltage as the COMMON terminal. This further increases the leakage resistance and common mode rejection by about ten times. The voltage used to drive the GUARD terminal should be obtained from a separate source or by means of a voltage divider connected directly across the source so that the leakage currents do not cause voltage drops across impedances in the circuit under measurement.

13. In the 1 microvolt to 1 millivolt ranges, a 10-megohm resistor is connected directly across the input of the instrument. The input resistance may be increased on these ranges by disconnecting the 10-megohm resistor where it attaches to the RANGE switch. However, the input resistance will no longer be well defined. Typical input resistances with the 10-megohm resistor removed are as follows:

RANGE	INPUT RESISTANCE
1 μV	300 megohms
3 μV	1,000 megohms
10 μV	3,000 megohms
30 μV to 1 mV	10,000 megohms

Learning Event 3:
DESCRIBE THEORY OF OPERATION OF THE 845AR NULL DETECTOR

1. As shown in Figure 4-6, the Model 845AR is a photochopper stabilized amplifier with the overall gain of the amplifier being precisely controlled by negative feedback. The instrument's main circuits are an input range divider, a photocell modulator, an ac amplifier, a synchronous demodulator, a dc amplifier, a meter, an isolation converter, a neon drive, an 84 Hz multivibrator, a supply rectifier, and a rectifier filter.

a. The input range divider provides a fixed input impedance to signals of less than 1 millivolt while allowing reduction of input signals about 1 millivolt. Photochoppers modulate the input signal to the ac amplifier at 84 Hz. The drive signal for the photo modulator is provided by the neon drive which is composed of neon lamps driven alternately at 84 Hz by the 84 Hz multivibrator. Eighty-four Hz is used to provide the Model 845AR with an operating frequency asynchronous with the power line frequency and its harmonics. The 84 Hz multivibrator also drives the following circuits:

(1) The supply rectifiers which provide operating voltages for the amplifiers.

(2) The synchronous demodulator which demodulates the amplified ac signal.

(3) The isolation converter which produces the meter and isolated recorder output. The entire amplifier and the secondaries of both transformers are surrounded by a guard shield which permits the use of external guard voltages.

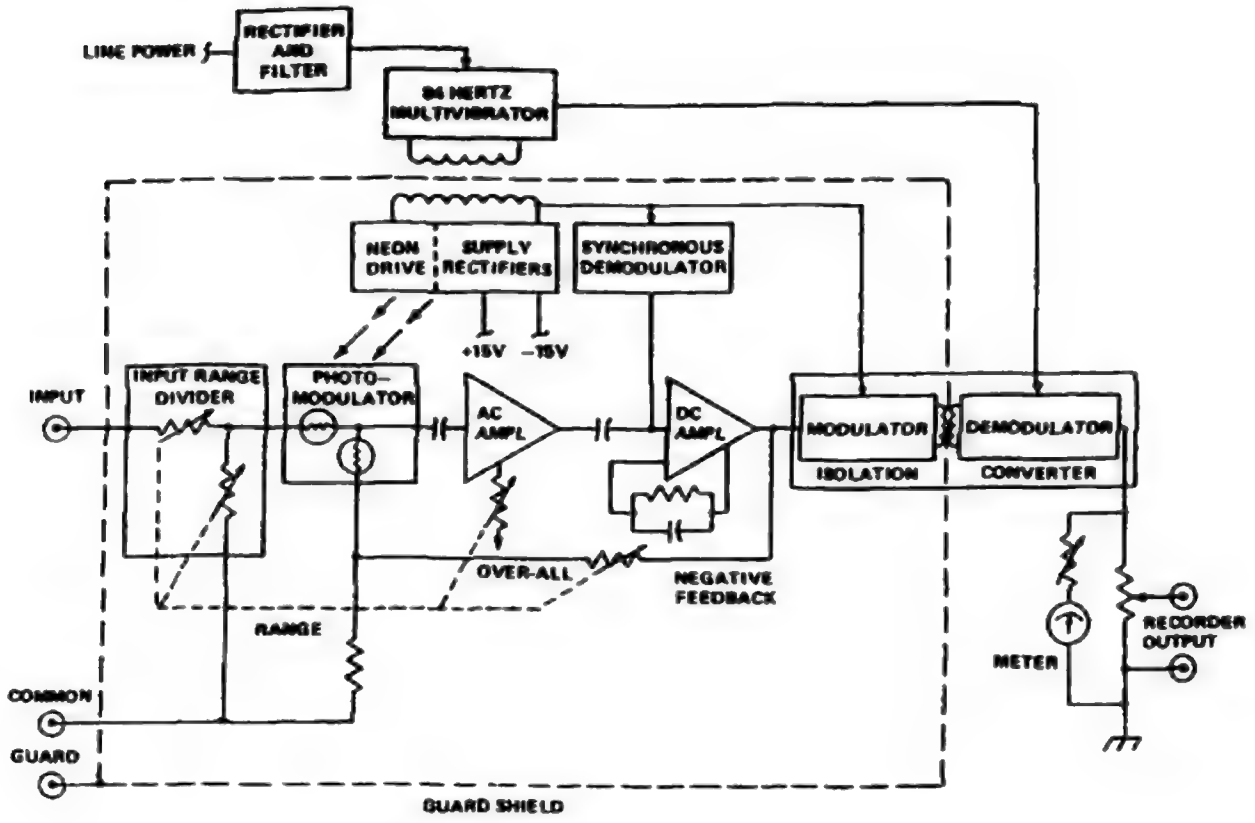


Figure 4-6. Model 845AR block diagram

b. The ac amplifier is a high impedance amplifier whose gain is controlled by the resistance selected by the RANGE control. The amplified ac signal is then detected by the synchronous demodulator.

c. The synchronous demodulator is driven by the 84 Hz reference signal and detects the amplified ac signal. The detected ac signal is then amplified by an ac amplifier whose gain is controlled by fixed feedback. The output signal of the ac amplifier is applied to the isolation converter which drives the isolated recorder output and the meter which indicates the polarity and magnitude of the measured voltage. This same ac signal is also fed back to the input of the ac amplifier to control overall amplifier gain. The feedback ratio is determined by the setting of the RANGE control and allows overall amplifier gain to be precisely controlled.

2. The Model 845AR High Impedance Voltmeter - Null Detector circuit theory of operation description is contained in the following paragraphs. The functional schematic diagram (fig 4-7) should be used as an aid in understanding circuit theory, and in troubleshooting.

a. Input power transformer T201 receives 115 volts ac, or 230 volts ac if the instrument is so wired, through the power switch, S1. The primary winding of T201 is constructed in such a manner as to utilize either 115 volts ac input, windings parallel, or 230 volts ac, windings in series. Fuse, F1, protects the Model 845AR circuitry from overloads.

b. The secondary voltage of T201 is rectified by bridge rectifier CR201 through CR204. The bridge rectifier output voltage is filtered by C201 and regulated by zener CR207. This regulated output voltage is used as the operating voltage for the 84 Hz multivibrator.

c. The 84 Hz multivibrator is used to provide synchronous drive voltages and dc operating voltages for the Model 845AR amplifier circuits free from any power line frequency variations and harmonics. The multivibrator is a transformer-coupled free running multivibrator composed of transistors Q201 and Q202, transformer T202, and frequency determining components C203 and R206 through R208. Variable resistor R206 is used to adjust the frequency of the multivibrator to 84 Hz. The voltage at the secondary of T202 is rectified by CR104 and CR105 to produce the positive and negative 15 volt dc operating voltages for the amplifier circuits. The same winding furnishes the synchronous demodulator and isolation converter drive signals and is tapped at a higher voltage level to drive the neon lamps DS101 and DS102. These neon lamps provide the drive signal for the photocell modulators V101 and V102.

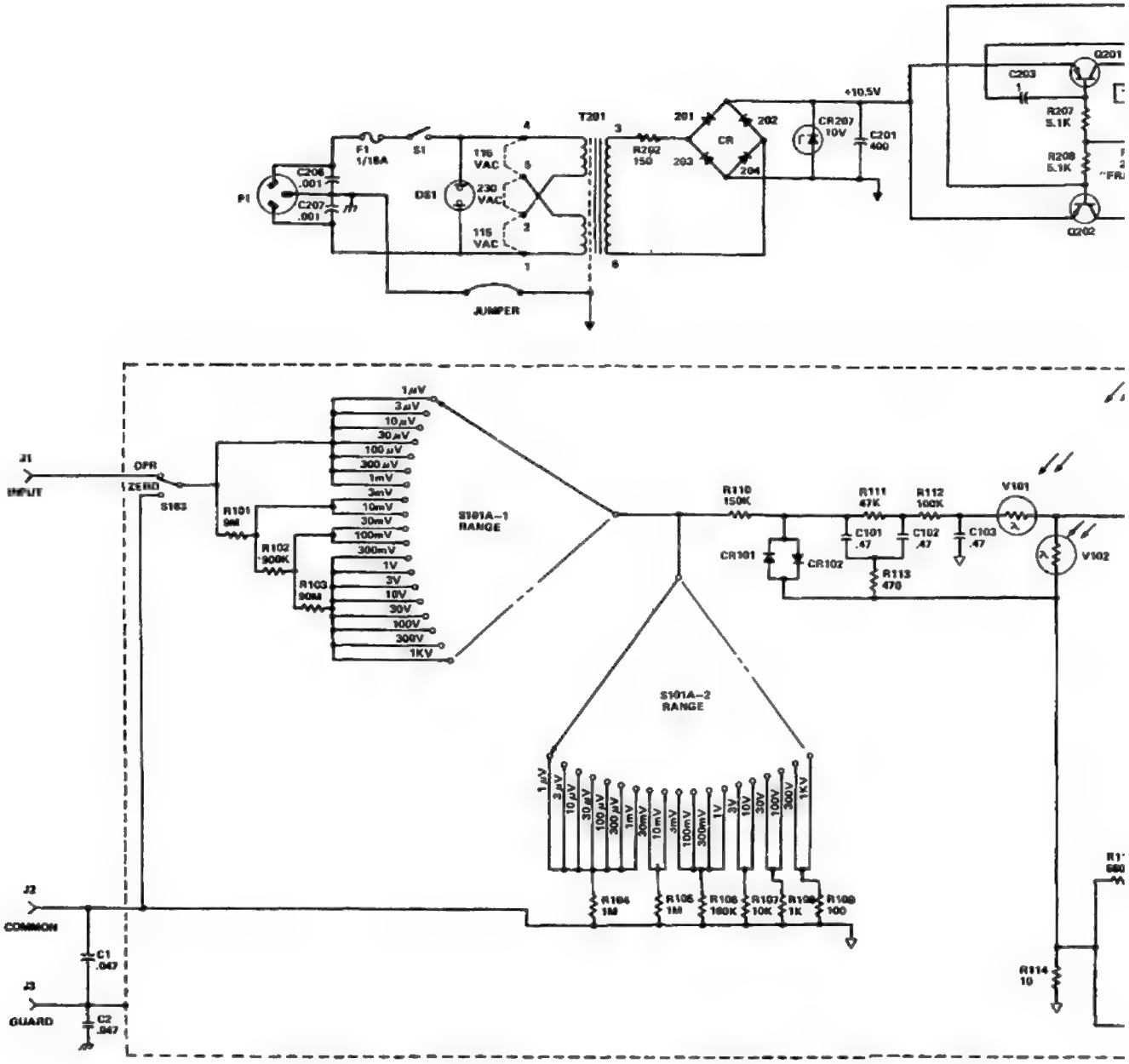


Figure 4-7 (fo). Functional schematic diagram of Model 845AR High Impedance Voltmeter

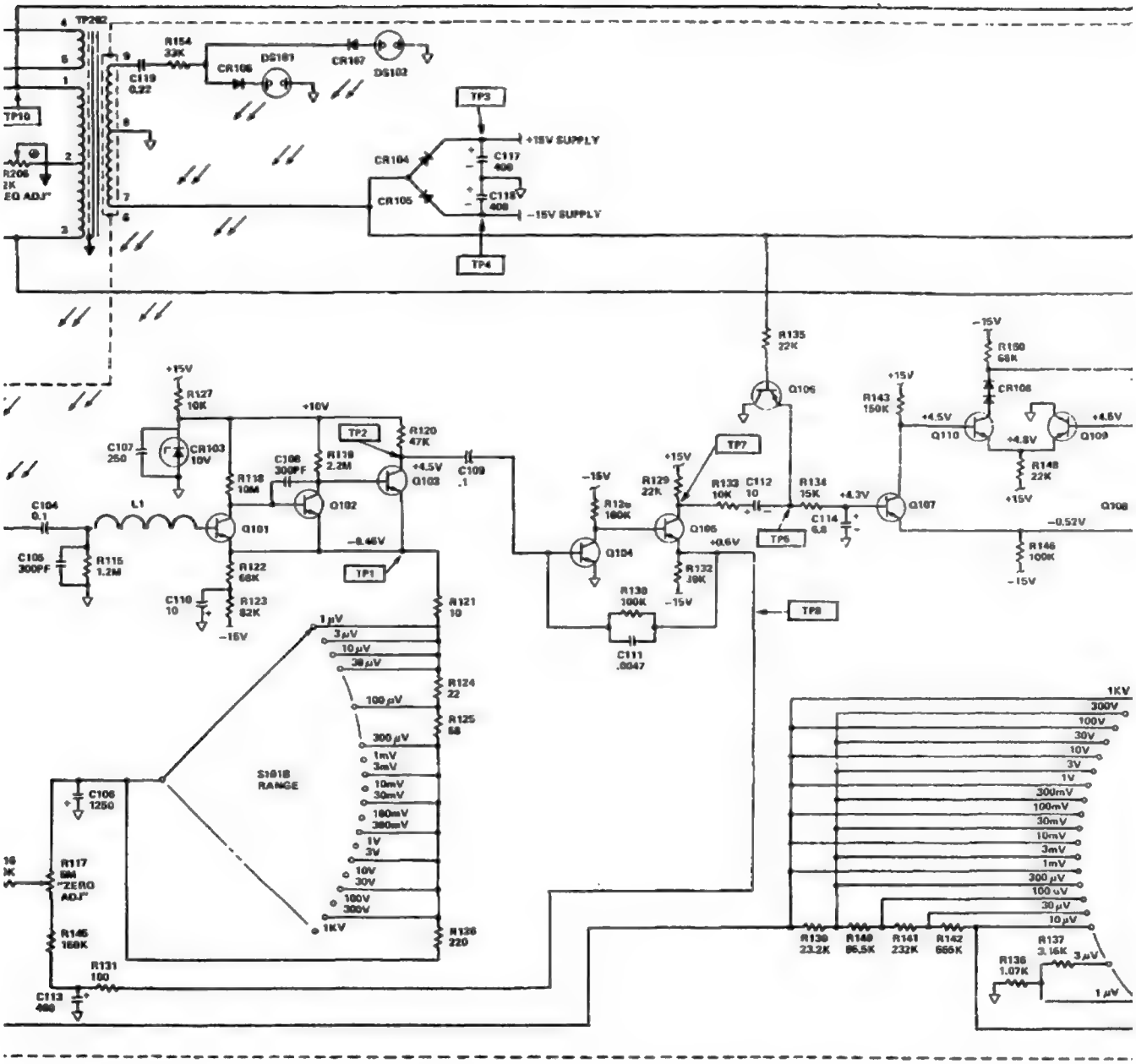


Figure 4-7a (fo). Functional schematic diagram of Model 845AR High Impedance Voltmeter

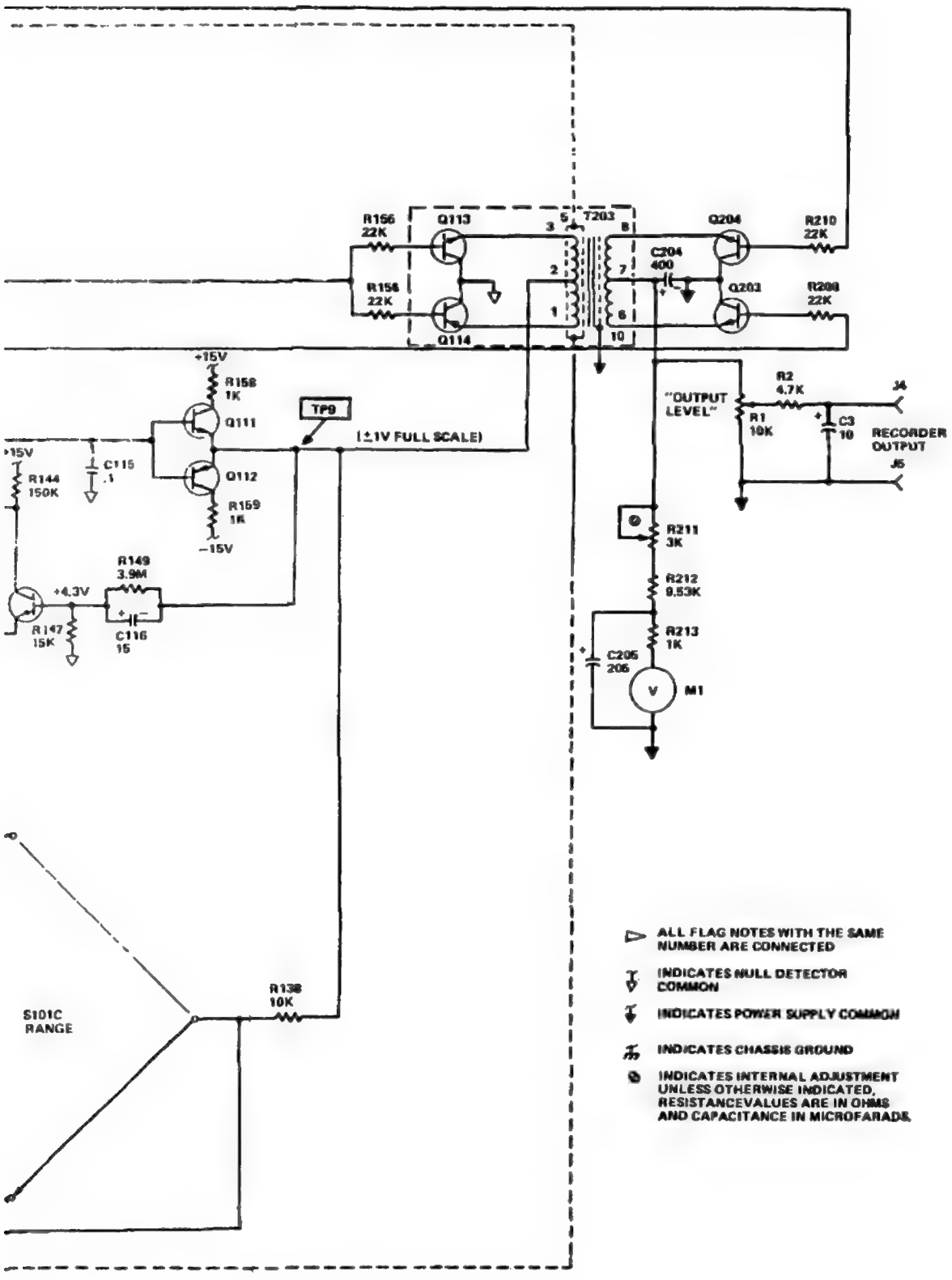


Figure 4-7b (fo). Functional schematic diagram of Model 845AR High Impedance Voltmeter

d. The basic full-scale sensitivity of the Model 845AR is limited to a maximum of 1 millivolt. Therefore, input signals above this value must be reduced. The input divider consists of R101 through R109 and RANGE switch S101A. On ranges being a multiple of 1, input voltages above 1 millivolt are divided down to 1 millivolt or less, upon selection of the proper range. On ranges being a multiple of 3, input voltages above 1 millivolt are divided down to 300 microvolts or less, upon selection of the proper range. On ranges of 1 millivolt and below, a 10-megohm resistor, R104, is connected across the input to provide a fixed value of input impedance.

e. The input signal from the input divider is filtered by a three stage, low-pass filter composed of R110, C101, R111, C102, R112, and C103. This filter reduces any ac voltage having a frequency above 1 Hz. The filtered dc voltage is then square-wave modulated by photocell modulators V101 and V102, which are driven by DS101 and DS102. The resulting square-wave signal is coupled through C104 and amplified by Q101, Q102, and Q103 which form a three-stage amplifier having a high input impedance. The gain of the ac amplifier is controlled by the common emitter resistance selected by the RANGE switch S101B. Maximum gain is used on the 1, 3, 10, and 30 microvolt ranges and is gradually reduced by the selection of R124 through R126 as the range is increased. The output of Q103 is capacitively coupled to a two-stage current amplifier composed of Q104 and Q105. The current amplifiers have a constant gain controlled by fixed negative feedback through R130 and C111.

f. The synchronous demodulator detects the magnitude and phase of the amplified signal. The 84 Hz drive signal is applied to the base of transistor Q106 which references the synchronous demodulator to the same phase as the photocell modulator. The demodulated signal is filtered by R134 and C114 before being applied to the dc amplifier.

g. The dc amplifier amplifies the detected dc signal from the synchronous demodulator. Transistors Q107 through Q112 comprise a two-stage differential amplifier with a complementary emitter-follower output. Negative feedback through R149 and C116 is applied to the base of Q108 and controls the dc amplifier gain. The output from the common emitter of Q111 and Q112 is one volt dc for a full range input on any range, which drives the isolation converter. Overall negative feedback through the resistive network of R138 through R142 and R114 is controlled by the position of the RANGE switch S101C. This negative feedback allows precise control of the overall gain of the Model 845AR amplifiers.

h. The isolation converter drives the recorder output and meter while providing isolation from the Model 845AR amplifier circuitry. The output signal from the amplifier is applied to the transistors Q113 and Q114. An 84 Hz reference drive signal is applied to the bases of transistors Q113 and Q114 which causes modulation of the dc input signal to occur. The resulting modulated signal is coupled to the secondary of T203 where transistors Q203 and Q204 demodulate secondary signals occurring at their 84 Hz base signal rate. Capacitor C204 charges to the peak of the demodulated signal and discharges through the OUTPUT LEVEL control R1, R211 through R213, and the meter M1. The

meter M1 indicates the polarity and magnitude of the input voltage. Capacitor C3 and resistor R2 filter the resulting dc output voltage for the recorder output.

Learning Event 4:
DESCRIBE TROUBLESHOOTING THE 845AR NULL DETECTOR

1. The purpose of troubleshooting is to locate and correct as quickly as possible any deficiency in operation. The causes and remedies of the more common troubles that may occur are listed in the troubleshooting chart, Figure 4-8. Waveforms useful for troubleshooting are given in Figures 4-9 through 4-14. A complete understanding of the theory of operation and familiarity with the schematic diagram is the best way to locate and correct the cause of any malfunction.

SYMPTOM	PROBABLE CAUSE	FAULT ISOLATION PROCEDURE
Blows fuses.	Short circuit across secondary of T201.	Test for short circuit between pins 3 and 6.
	Shorted turn in T201.	Unsolder R202 in secondary of T201. A shorted turn will require almost as much current as normal operation.
	Defective CR201 through CR206.	Measure voltage of C201. Should be 10.5 volts. If near zero, replace CR201 through CR206, as necessary.
Photo Modulator inoperative. (Neon lights out)	Defective Q201 or Q202.	If voltage of C201 is less than 7 volts, and batteries are charged, replace Q201 and/or Q202.
	Open winding on T202, or open C203.	Waveform of TP10 should agree with Figure 4-9. If square wave is absent, T202 or C203 is defective.
	No drive to neon lamps DS101 and DS102.	A square wave of over 200 volts peak-peak should be present between pin 9 of T202 and the GUARD terminal. If not, T202 may be defective.

Figure 4-8. Troubleshooting chart

SYMPTOM	PROBABLE CAUSE	FAULT ISOLATION PROCEDURE
Meter movement inoperative.	Dead meter. Defective auxiliary supply.	Check meter with an ohmmeter. Panel meter should peg. Measure voltages at TP3 and TP4. If one voltage is near zero, check the associated diode and capacitor. If both voltages are zero, T202 is defective.
Meter pegs or wanders.	Meter mechanically stuck. Defective amplifier	Using an oscilloscope with dc coupling, measure waveforms at TP6. If waveforms agree with Figure 4-10 check Q111, Q112, Q109, Q110, Q107, and Q108 by replacement. If waveforms are not correct, then: (a) Waveform at TP6 looks more like waveform at TP7, Figure 4-11 Q106 is open. (b) No change in waveform at TP6 as ZERO control is rotated. R114 is shorted, base of Q101 is shorted, V101 or V102 is shorted. (c) Waveform at TP6 looks like a square wave. Measure waveform at TP7. If square wave disappears and waveform at TP7 is correct, C112 is shorted. If waveform is not correct, remove Q104 and measure waveform at TP2, Figure 4-12 If square wave persists, short junction of R115, C104, C105, and base of Q101 to common. If square wave disappears, remove short and transfer short to R112, C103, and V101 junction. If square wave returns, a photocell is defective, or C104 is shorted. If square wave does not return, move the short to the end of R110 that connects to RANGE switch. If signal reappears, CR101 or CR102 is defective. If square wave does not reappear, the RANGE switch is defective. (d) No signal at TP6. If there is also no signal at TP7, Q106 is probably shorted. If Q106 is satisfactory, measure waveform at TP2. If there is still no signal, C107, CR103, Q101, Q102, or Q103 is defective.
Erratic or unstable condition when measuring a voltage or zeroing instrument.	S103 Erratic Contact.	Replace or burnish contacts with crocus cloth.
Meter deflects in one direction, only.	Open winding on T203, defective Q113, Q114, Q203, or Q204.	Check and replace as necessary.
Slower response in negative direction.	Leaky C120.	Test and replace if necessary.
Measurements are low on high-sensitivity.	Shorted C116.	Test and replace if necessary.
Poor stability.	Defective CR207.	Replace if necessary.

Figure 4-8. Troubleshooting chart (continued)

SYMPTOM	PROBABLE CAUSE	FAULT ISOLATION PROCEDURE
Noise on 1, 3, and 10 uv ranges.	Dirty or defective Q101, or defective Q102. Defective chopper	Measure waveform at TP2. Figure 4-13 waveform shown is normal. Additional noise at TP2 is due to dirty Q101 or defective Q102. Remove Q111 and Q112, and apply an input of 1 mv. Observe waveform at TP1. For waveform shown in Figure 4-14. (a) Excessive noise can be caused by poor positioning of neon lamps. (b) Smaller waveform can be caused by slow response of photocells; if so, replace cells.
Unguarded leakage poor.	Dirty grommets. Leakage in T202 or T203.	Clean according to paragraph 3. Test and replace if necessary.
Guarded leakage poor	Leakage in T202 or T203, or pins touching circuit board. Contaminated binding posts.	Test and repair as necessary. Clean according to paragraph 3.
Poor overload recovery.	Defective C101, C102, C103, C120, CR101, CR102, or R110.	Test and replace as necessary.

Figure 4-8. Troubleshooting chart (continued)

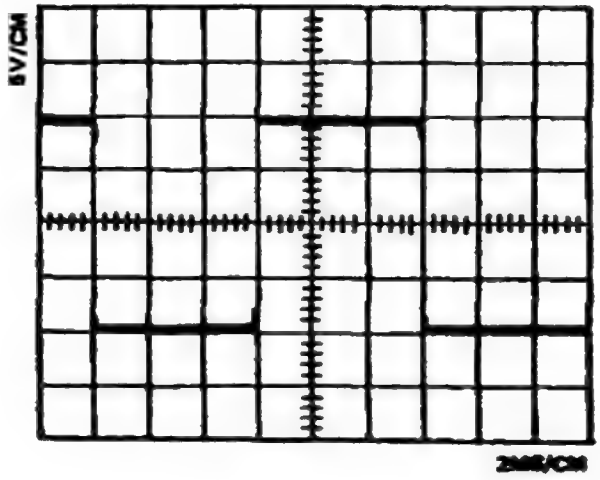


Figure 4-9. Waveform at TP10

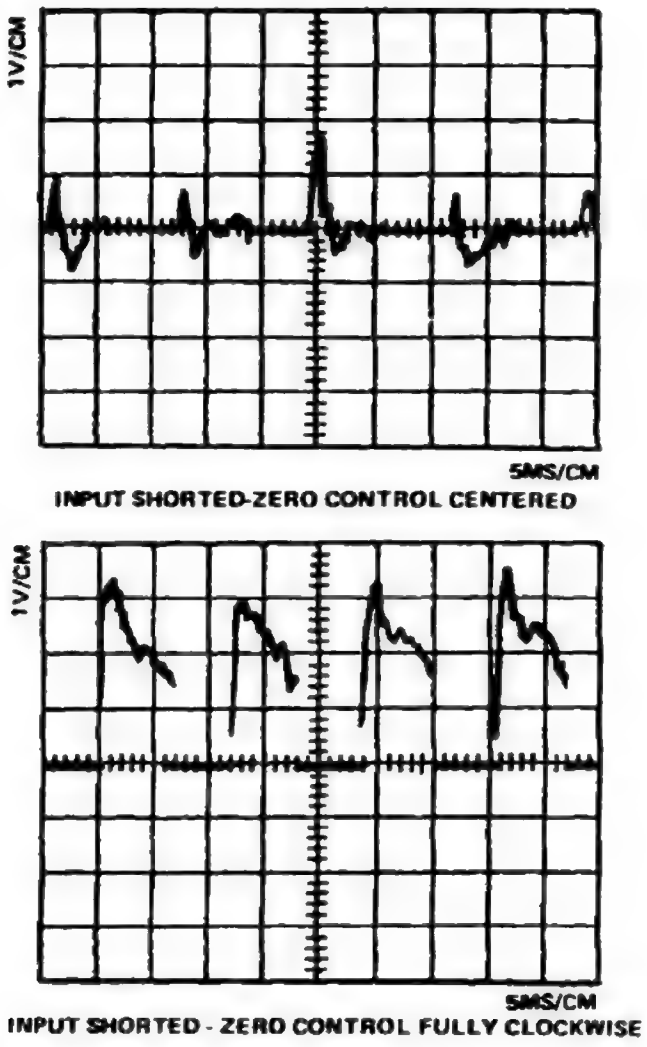


Figure 4-10. Waveforms at TP6

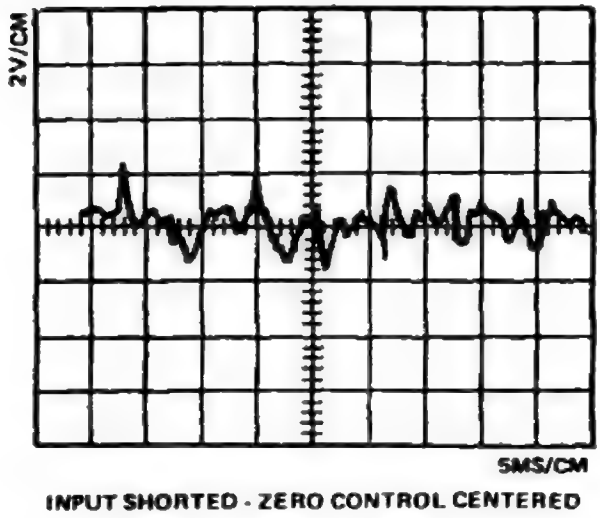


Figure 4-11. Waveform at TP7

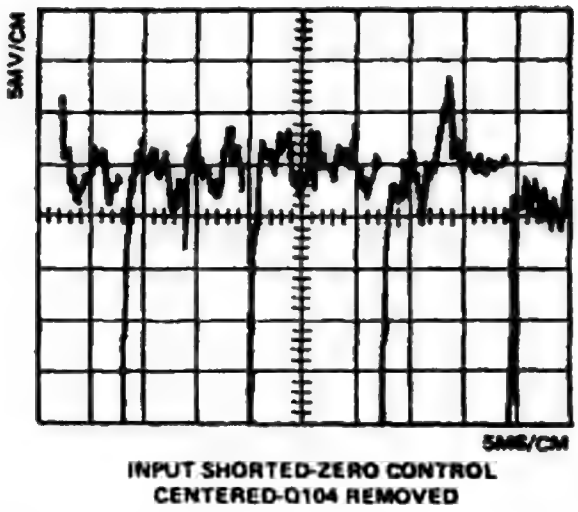


Figure 4-12. Waveform at TP2 - Q104 removed

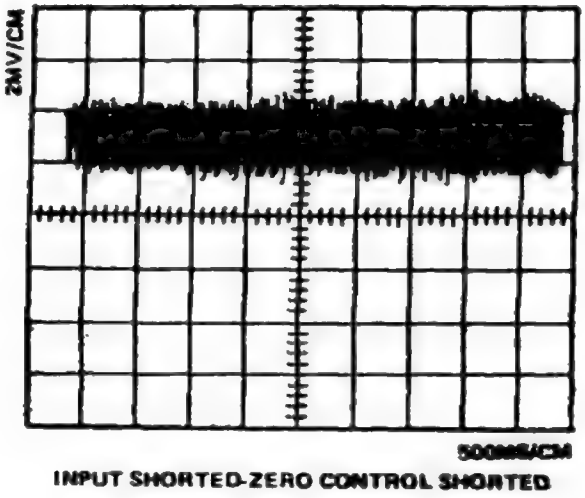


Figure 4-13. Waveform at TP2

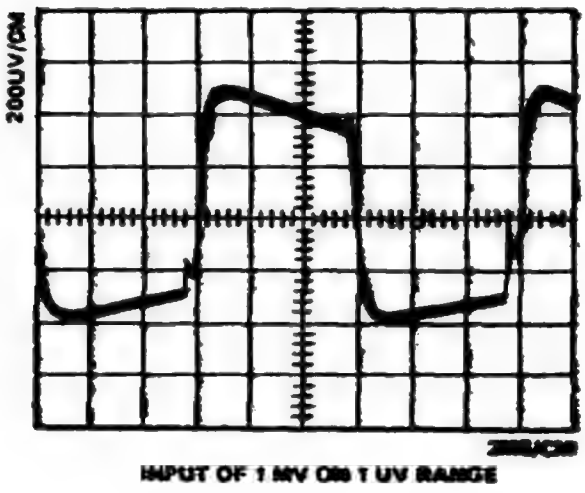


Figure 4-14. Waveform at TP1

2. Troubles may sometimes be located by a thorough visual inspection. This may be accomplished by looking for the following symptoms:

a. Accumulations of dirt, dust, moisture, or grease. Remove contamination as outlined in paragraph 3.

b. Scorched or burned parts. Damage of this type is usually caused by other defective components. Determine the cause of damage before replacing components.

c. Cracks, cuts, and other damage to the polyethelene grommets or to the circuit boards.

CAUTION

Do not touch the polyethelene grommets. Contamination will cause excessive electrical leakage.

Lesson 4
PRACTICE EXERCISE

1. What is the accuracy of the 845AR Null Detector?

   a. ±(3% end scale + 0.1 microvolt)
   b. ±(3% end scale + 1.0 microvolt)
   c. ±(1% end scale + 0.3 microvolt)
   d. ±(1% end scale + 3.0 microvolt)

2. What is the input impedance of the 845AR NW1 Detector above 100 millivolt range?

   a. 10 megohm
   b. 100 megohm
   c. 500 megohm
   d. 1 megohm

3. Which terminal is strapped to the common terminal on the 845AR Null Detector?

   a. Ground
   b. Negative
   c. Guard
   d. Positive

4. What uses can the 845AR Null Detector be used for?

   a. Voltmeter, voltage divider, and amplifier
   b. Amplifier, voltmeter, and bridge detector
   c. Differential voltmeter, voltage divider, and bridge detector
   d. Bridge detector, differential voltmeter, and amplifier

5. What components provide the drive signal for the photocell modulators V101 and V102 in the 845AR Null Detector?

   a. DS101 and DS102
   b. DS1 and DS2
   c. CR104 and CR105
   d. CR106 and CR107

6. What is the output of Q111 and Q112 with a full range input on any range of the 845AR Null Detector?

   a. 1 volt ac
   b. 1 millivolt dc
   c. 1 volt dc
   d. 100 microvolts dc

7. The meter pegs are on the 845AR Null Detector. There is NO charge in the waveform at TP6 as the ZERO control is rotated. What is the probable cause?

   a. V101 shorted
   b. V102 open
   c. C112 shorted
   d. Q106 shorted

8. The waveform at TP215 is smaller than normal in the 845AR Null Detector. What is the probable cause?

   a. Photocells are bad
   b. T201 is bad
   c. CR104 open
   d. C205 shorted

LESSON 5
DIFFERENTIAL VOLTMETER MODEL 887AB/AN

TASK

Describe and identify theory, terminology, and operation of Differential Voltmeter Model 887AB/AN.

CONDITIONS

Given information and illustrations about theory, terminology, and operation of Differential Voltmeter Model 887AB/AN.

STANDARDS

Demonstrate competency of the task skills and knowledge by correctly responding to 80 percent of the multiple-choice test covering Differential Voltmeter Model 887AB/AN.

REFERENCES

Technical manual for Fluke Model 887AB/AN Differential Voltmeter.

Learning Event 1:
DESCRIBE THE DIFFERENTIAL VOLTMETER

1. Among the most accurate and reliable measuring devices you will encounter are the differential voltmeters. The high accuracy, portability, and compactness of the differential voltmeter make this instrument ideal for precise measurement of almost any ac or dc voltage. Ease of operation, inherent protection from accidental overload, and high reliability contribute to the outstanding performance that assures stability for both production-line testing and laboratory measurement. This instrument is capable of being used as a voltmeter, as a precision potentiometer, and as a megohmmeter for measurement of high resistance. It can also be used to measure the excursions of a voltage about some nominal value.

2. Some of the advantages of differential voltmeters are: circuit loading is negligible, error due to meter reading interpolation is eliminated, error due to parallax is reduced, and ease of operation.

3. The big disadvantage of all passive-type meters is their loading effect. In Figure 5-1, a 1000-ohm-per-volt voltmeter with an accuracy of 0.1 percent is used to measure 10 Vdc across a 10-kilohm resistor.

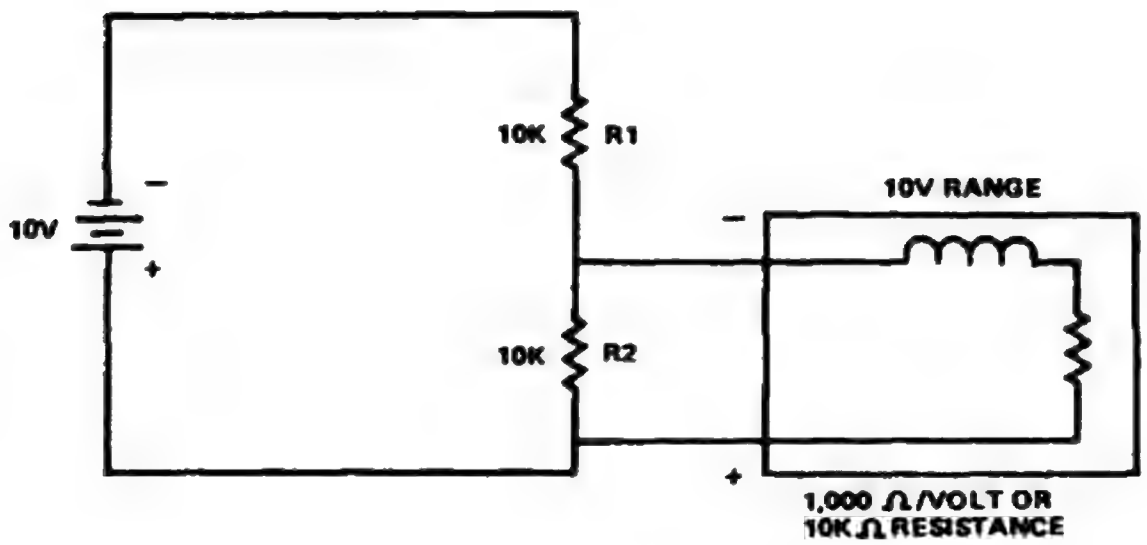


Figure 5-1. Passive meter loading

Note that when this meter is placed across the resistor, it actually creates an alternate 10-kilohm current path around R2. Where the total circuit resistance was 20,000 ohms with a current flow of 0.5 milliampere, now there is a total resistance of 15,000 ohms and the current flow is 0.67 milliampere. (Ten volts divided by 20 kilohms equals 0.5 milliampere and 10 volts divided by 15 kilohms equals 0.6667 milliampere.) This is what is meant by loading. Where the voltage dropped across R2 was 5 volts and it could have been in tolerance, the meter will indicate close to 3.3 volts, or out of tolerance by 35 percent.

4. A way of greatly reducing this loading problem is to use a very high impedance input circuit to the meter. However, it should be pointed out that there is still some loading, although very minor. By using a Vacuum Tube Volt Meter (VTVM), you do reduce the effects of loading; however, because of the extreme cost involved, most VTVMs are about 3 percent. So we have lost our accuracy. What we need then is a meter with an accuracy of better than 0.1 percent and one that produces no loading effect.

5. Suppose we were to connect a battery of exactly the same potential as that dropped across R1 as shown in Figure 5-2. No current would flow from A to B, but we would be able to measure the actual voltage present at A with no loading of the original circuit.

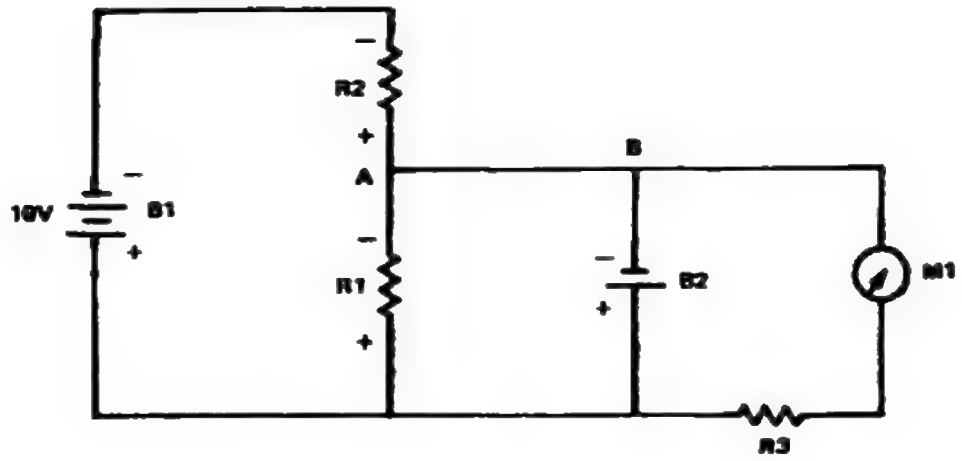


Figure 5-2. Basic null

6. How do we know when the opposing voltage (second battery) or the nulling voltage is exactly the same as that across R1? Note the hookup in Figure 5-3. If any difference in EMF exists between points A and B, a current will flow in one direction through galvanometer M2. Thus by varying R4 until M2 indicates no current flow, we can set the potential at A to equal that at B. Then we will measure EMF at B with M1 and, in effect, we have measured the EMF at point A with no loading of the original circuit.

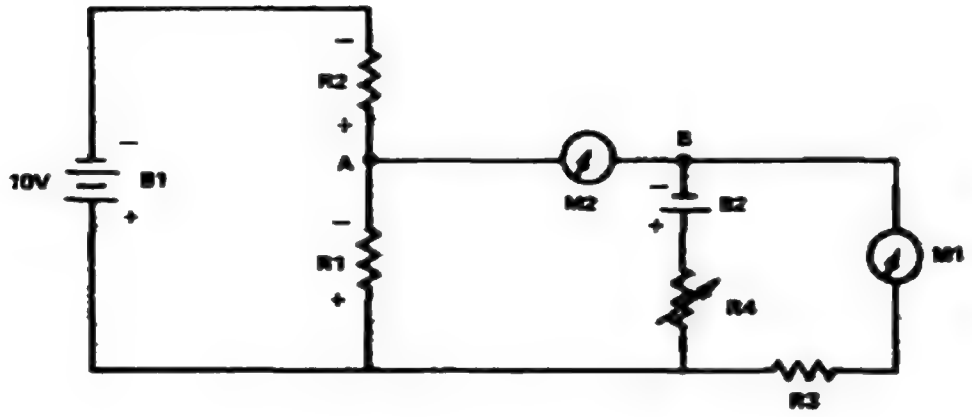


Figure 5-3. Null with galvanometer

7. However, we have two problems. Varying R4 presents a varying load to B2, which would present a problem if B2 were replaced by a power supply. M1 cannot give us any greater accuracy than the meter itself, or about 3 percent.

8. Now we come to the basic null-type or potentiometric meter (fig 5-4). M1 is a galvanometer. Any time there is a difference of EMF between A and B, current will flow through M1. The wiper arm of the voltage divider is moved up or down, changing the applied null voltage until current does not flow and the voltage at B is exactly equal to the voltage being measured.

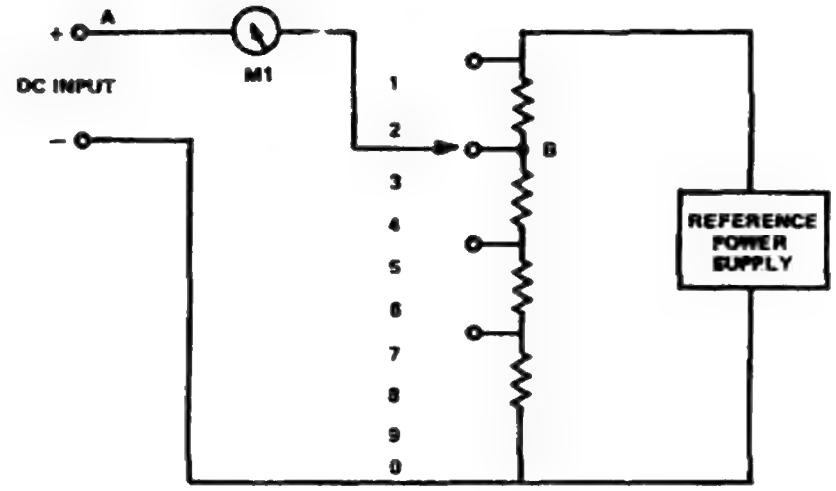


Figure 5-4. Basic null-type meter

9. The voltage divider is much more complicated than shown, but the results are the same. The voltage output can be read directly to five digits, using a mechanical readout system (example: 345.64 VDC). As the wiper arm is moved up or down, it mechanically changes these numbers to correspond to the voltage of B.

10. Note in Figure 5-5 that when null is obtained (null being the point where both voltages are the same and no current flows through the galvanometer) that exactly the same load is felt by the reference supply, regardless of where the voltage divider is set or what the input voltage is.

11. The only remaining point to cover is the measurement of AC voltage. Shown in Figure 5-6 is a basic potentiometric meter with the following important points: Will measure ac or dc; will not load circuit; because of mechanical readout, resolution is extremely good; two people could never read a 5-digit readout and obtain the same answer; and accuracy is better than 0.1 percent on dc.

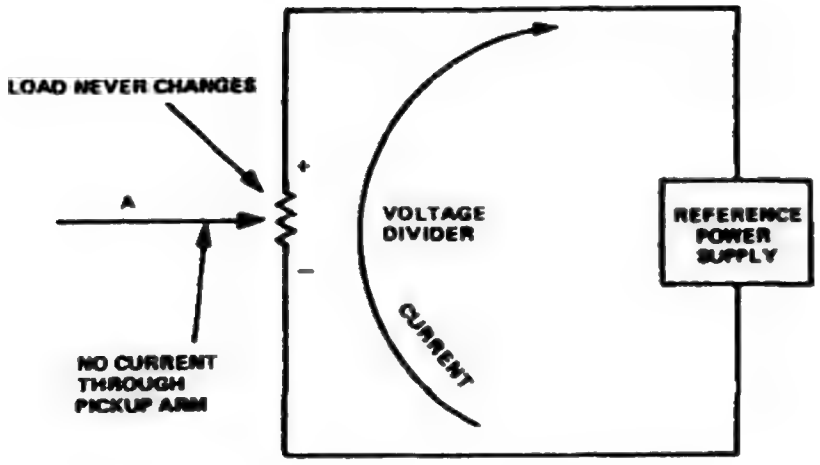


Figure 5-5. Constant load

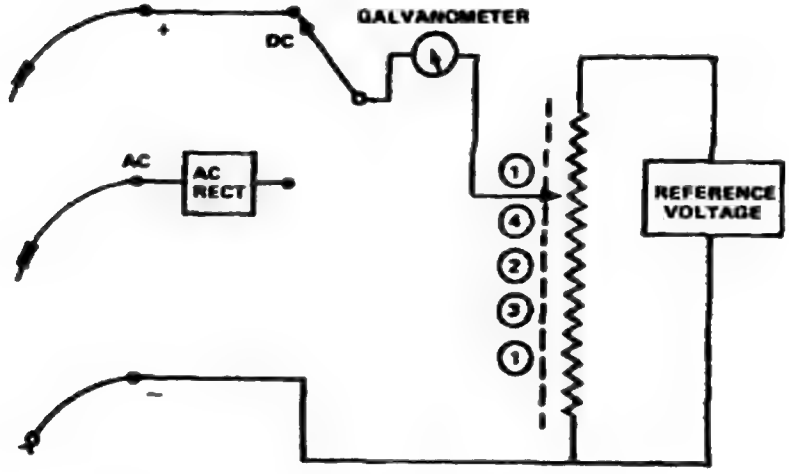


Figure 5-6. Basic potentiometer

Learning Event 2:
DESCRIBE THE 887AB/AN DIFFERENTIAL VOLTMETER

1. The Model 887A Differential Voltmeter is line-powered, and the Model 887AB Differential Voltmeter is either line- or battery-powered. Both instruments are half-rack width and are equipped with resilient feet and folddown bail for field or bench use. A single instrument may be mounted in a standard rack or two may be mounted side by side. The instrument is intended primarily

as a differential voltmeter. It may also be used as a conventional transistorized voltmeter for rapid voltage measurement, an accurate ac voltmeter, or a megohmeter for measurements of resistance from 10 meghoms to 11,000 megohms.

2. When used as a dc differential voltmeter, the instrument draws essentially no current from the unknown voltage source up to 11 volts. Above 11 volts the input resistance is 10 megohms. Common-mode voltage errors are virtually nonexistent in the Models 887A and 887B because of the high input-circuit leakage resistance, typically several hundred thousand megohms. In the Model 887AB, internal batteries permit isolation from power-line grounds with attendant reduction of ground loop errors.

3. When used as a dc differential voltmeter, the 887A operates on the potentiometric principle. An unknown voltage is measured by comparing it to a known adjustable voltage with the aid of a null detector. An accurate standard for measurement is obtained from an 11-volt dc reference supply derived from a pair of temperature-compensated zener diodes. The known adjustable reference voltage is provided by a Kelvin-Varley voltage divider with four decades of Fluke precision wire-wound resistors and a high-resolution interpolating vernier that are set accurately by five voltage readout dials to give a seven-digit readout. In this way, the 11 volts can be precisely divided into increments smaller than 10 microvolts. The unknown voltage is then simply read from the voltage dials. For voltages between 11 and 1100 volts dc, an input attenuator divides the unknown voltage by 100 before it is measured potentiometrically. When used as an accurate ac voltmeter, the 887A operates essentially the same as for dc differential measurements. The ac input voltage is converted to a dc voltage and this dc voltage is measured by comparing it to a known adjustable reference voltage.

4. Specifications.

a. As a differential voltmeter.

DC accuracy. ±(0.0025% of input + 0.0001% of range + 5 μV) from 0 to 1100 Vdc at 23°C (nominal calibration temperature), less than 70% relative humidity. ±(0.005% of input +5 μV) from 0 to ± 1100 Vdc within 16°C to 32°C (60°F to 90°F) temperature range, at less than 70% relative humidity. Derate accuracy outside this temperature range at 0.00035% to extremes of 0°C and 50°C (32°F and 122°F).

Voltage ranges. 1, 10, 100, 1000 V ac and dc with 10% overranging capability on each range.

Null ranges. 100 uV through 100 V end scale ac and dc, in 7 ranges. DC input resistance. Infinite at null from 0 to ±11 Vdc. 10 megohms above ±11 Vdc.

Meter resolution. 1 ppm of range (1 μV maximum).

Voltage dial resolution. 1 ppm of range (1 μV maximum).

b. As a conventional voltmeter.

AC accuracy. ±3% of range within frequency and voltage ranges listed under "ac accuracy as a differential voltmeter."

DC accuracy. ±3% of range.

c. General.

(1) Electrical design. Completely solid-state.

(2) Input resistance of null detector. 10 megohms for 2 least sensitive null ranges, all input ranges; 1 megohm for 2 most sensitive null ranges; all input ranges.

(3) Reference element. Temperature-compensated zener diode, temperature coefficient less than 1 ppm/°C over operating temperature range.

(4) Regulation of reference supply. 0.0002% for 10% line voltage change.

(5) Stability of reference supply. 0.0005% peak-to-peak per hour. 0.0007% peak-to-peak per day. 0.0013% peak-to-peak per 60 days.

(6) Stability of instrument. 0.00025% peak-to-peak per 60 days.

(7) Accuracy of off-null deflection. ±5% of null range (±3% with voltage dials at zero).

(8) Kelvin-Varley divider accuracy. ±0.0012% of setting from 1/10 of full scale to full scale. ±0.0012% terminal linearity below 1/10 full scale.

(9) Recorder output. Adjustable from 0 to ±20 mv minimum for full scale right and left deflection.

(10) Polarity. Front panel switch selects ±DC, -DC and AC.

(11) Warmup time. dc 30 seconds; ac one minute.

(12) Common mode rejection. 130 db dc; 85 db at 60 Hz; 70 db at 400 Hz.

NOTE

Battery operation of Model 887AB provides complete isolation from power system ground, for elimination of error due to ground loops.

(13) Operating temperature range. 0°C to 50°C (see accuracy)).

(14) Storage temperature range.

(a) Model 887A, -40°C to +70°C (-40°F to 158°F).

(b) Model 887AB, -40°C to -60°C (-40°F to +140°F).

(15) Shock. Meets requirements of MILT-945A and MIL-S-910B.

(16) Input power. Model 887A 115/230 Vac ±10%, 50 to 440 Hz; Model 887AB 115/230 Vac ±10%, 50 to 440 Hz and rechargeable battery operation (minimum 30 hours operation on full charge).

(17) Weight. Model 887A approximately 13 lbs, Model 887AB approximately 14 lbs.

(18) Size. 7 in high x 8 1/2 in wide x 14 3/4 in deep.

Learning Event 3:
DESCRIBE OPERATION OF THE 887AB/AN DIFFERENTIAL VOLTMETER

1. The input power connections of the instrument are normally factory-wired for 115-volt operation. 230-volt input power connections are described on a decal fastened to the power transformer (fig 5-7). Input power connections are effected through a three-wire power cord. The third wire is a ground wire to connect the instrument chassis to the power system ground. When a two-to-three wire adapter is used, fasten the green wire to the power-system ground.

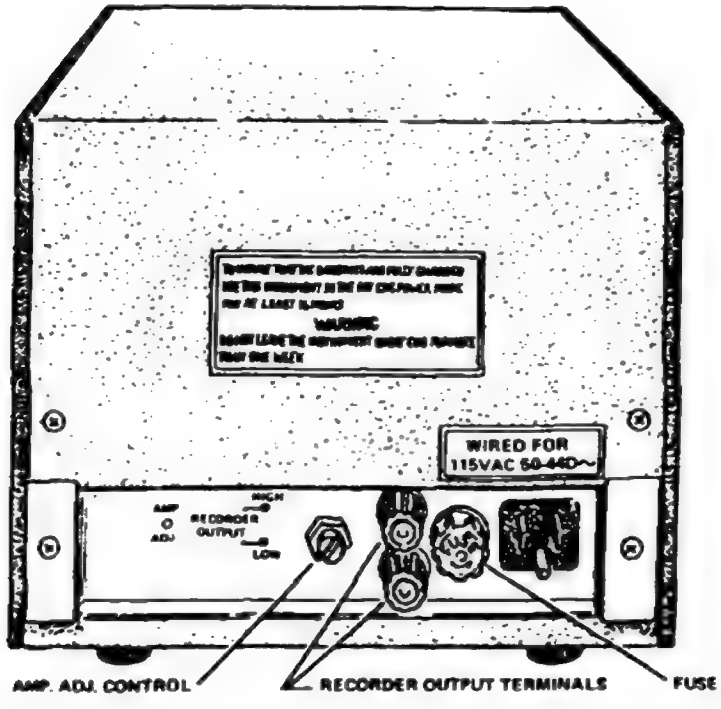


Figure 5-7. Location and function of rear panel control

2. The batteries in the Model 887AB can be checked by turning the POWER switch to BAT CHECK (fig 5-8). If the batteries contain a satisfactory charge, the meter needle will come to rest in the BATTERY OK region and remain there for at least 10 seconds. If it does not, the batteries must be recharged according to the instructions of paragraph 3.

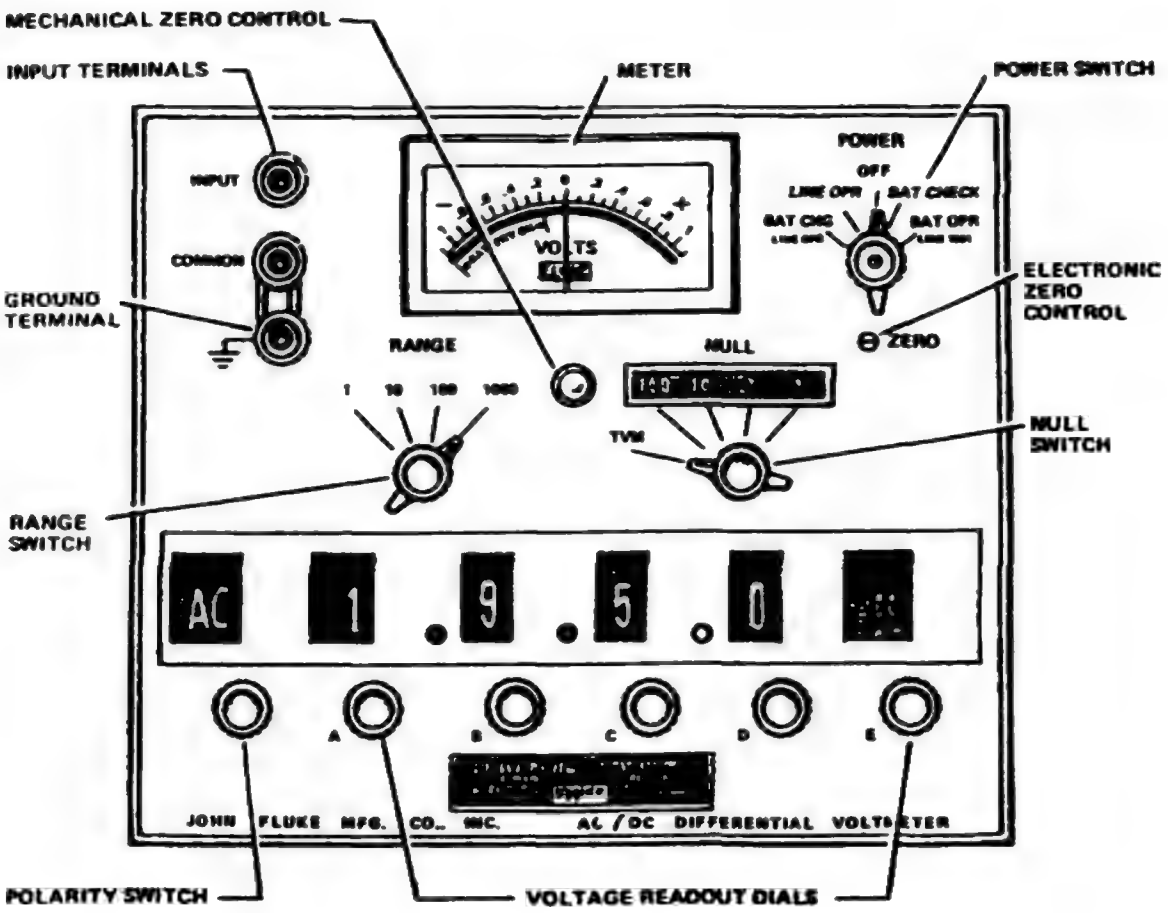


Figure 5-8. Location and function of front panel controls, Model 887A/AB

3. Should the BAT CHECK position of the power switch indicate low batteries, the following procedure would be used:

a. Connect power plug.

b. Set POWER switch to BAT CHG-LINE OPR.

c. Batteries will be fully charged and capable of at least 30 hours of operation after 16 hours of charging. While the batteries are charging, the instrument may be used the same as for line operation.

CAUTION

Since overcharging decreases battery life, it is recommended that the batteries be charged for less than 48 hours. When used properly, the batteries will give more than 200 charge-discharge cycles of operation.

4. In the absence of an input signal, the meter should indicate zero. If it does not, the meter circuits would be adjusted as follows:

a. With the input power disconnected for a least 3 minutes, the meter needle is set to zero with the mechanical zero control (fig 5-8).

b. The instrument is turned on and allowed to warm up for 5 minutes.

c. The RANGE switch is set to 1, the voltage readout dials to 0, and the NULL switch to 0.0001.

d. The INPUT post is shorted to the COMMON post and the electronic ZERO control is adjusted with a screwdriver for zero meter deflection.

e. The short is removed from the INPUT and COMMON posts.

5. When operating the instrument as a conventional voltmeter (NULL switch at TVM) four input-voltage ranges are available. They are 1, 10, 100, and 1000 volts, and are selected by the RANGE switch. Additional lower-voltage ranges are available by operating the instrument as a differential voltmeter with the voltage readout dials set to 0. In this case, the NULL switch determines full-scale meter calibration.

a. The desired full-scale deflection is selected with the RANGE switch.

b. The NULL switch is set to TVM.

c. The polarity switch is set to + or ac as desired.

d. The unknown voltage is connected to the INPUT and COMMON terminals. If one side is grounded, it is connected to the COMMON terminal.

e. The voltage magnitude is read on the meter scale. A positive voltage at the INPUT terminal will deflect the meter needle to the right.

6. When operating the instrument as a DC differential voltmeter, a dc differential voltmeter measurement can be performed more quickly if the order of magnitude of the unknown voltage is known at the outset. If unknown, it can be quickly measured in the TVM mode as described in paragraph 5. To measure the unknown voltage, the following procedure would be followed:

a. Correct meter zeroing is verified as in paragraph 4.

b. The RANGE switch is set to the lowest range setting that includes the unknown voltage magnitude.

c. The NULL switch is set to the least sensitive range (i.e., fully counterclockwise).

d. The voltage readout dials are set to the approximate magnitude of the unknown voltage.

e. The unknown voltage source is connected to the INPUT and COMMON terminals. If one of the voltage-source terminals is grounded, it is connected to the COMMON terminal.

f. The voltage readout dials are adjusted for a zero indication on the meter, while turning the NULL switch to successively more sensitive positions.

g. The magnitude of the unknown voltage is read from the readout dials.

h. Fluctuations in the unknown voltage can be measured by observing the excursions of the meter needle. Full scale meter calibration is determined by the setting of the NULL switch.

7. When operating the instrument as an ac differential voltmeter, if the approximate input voltage is not known, determine it by using the voltmeter in the ac TVM mode.

a. Correct meter zeroing is verified as in paragraph 4.

b. The RANGE switch is set to the lowest range setting that includes the unknown voltage.

c. The NULL switch is set to the least sensitive position (i.e., fully counterclockwise).

d. The voltage readout dials are set to the approximate magnitude of the unknown voltage.

e. The unknown voltage is connected to the INPUT and COMMON terminals.

f. The voltage readout dials are adjusted for a zero indication on the meter, while turning the NULL switch to successively more sensitive positions.

g. The magnitude of the unknown voltage is read from the readout dials.

h. Fluctuations in the unknown voltage can be measured by observing the excursions of the meter needle. Full scale meter calibration is determined by the setting of the NULL switch.

8. When recording voltage excursions about a nominal value, correct meter zeroing is verified as in paragraph 4 and the ac-dc polarity switch is set to the desired position.

a. The input voltage is connected between the INPUT and COMMON terminals. If one side is grounded, it is connected to the COMMON post. Deflection of the meter needle to the left indicates a negative voltage at the INPUT terminal. The polarity switch is turned to negative.

(1) The RANGE switch is set to the lowest range giving an on-scale deflection.

(2) The digital readout dials are set to the value determined in step (1).

(3) The NULL switch is turned to the lowest position that still allows excursions to stay on scale.

(4) The voltage deflections are observed on the meter. Deflections to the right indicate an increase in amplitude; to the left, a decrease in amplitude.

b. When recording voltage excursions, it must be remembered that the leakage resistance, recorder to ground, must be at least 10,000 megohms. Less resistance will impair the accuracy of the voltmeter. If the recording instrument has less than 10,000 megohms input resistance, an isolation amplifier must be used. The Fluke Model A88 is recommended for this application as it permits the use of any recorder without regard to input isolation characteristics.

c. To use the Model 887A with an isolation amplifier and recorder:

(1) The INPUT terminal is shorted to the COMMON terminal and the voltmeter switches are set to:

RANGE	10
NULL	1
readout dials	1.00000

The meter will indicate full scale deflection (-1.0). This feeds up to a maximum of 20 mv to the RECORDER output terminals, depending on the adjustment of the AMP ADJ control.

(2) The recorder and amplifier are energized. The isolation amplifier is connected to the RECORDER OUTPUT terminals.

(3) The AMP ADJ control is adjusted for the desired maximum deflection of the recorder.

(4) The short from the INPUT and COMMON terminals is removed.

(5) Excessive current leakage is checked as follows: A voltage is connected to the input of the Model 887AB/AN and its magnitude is measured in the most sensitive null range. The recorder leads are alternately connected and disconnected to the voltmeter. A meter deflection of more than one major scale division (10% of the null range) indicates excessive leakage.

9. One of the features of the 887AB/AN Differential Voltmeter is its ability to be used as a megohmmeter for rapid measurements of high resistance.

a. For the quick determination of resistance values in the range from 10 to 11,000 megohms the following procedure is followed:

(1) Correct meter zeroing is verified as in paragraph 4.

(2) The NULL switch is set to 1 and the RANGE switch to 10.

(3) The unknown resistance is connected to the INPUT and COMMON terminals. Short isolated leads are used to minimize errors due to lead leakage resistance.

(4) The readout dials are adjusted for full-scale meter deflection (-1.0). If full-scale deflection cannot be obtained with the NULL switch at 1, change it to 0.1 or 0.001.

(5) The value of the unknown resistance is determined from Figure 5-9.

RANGE OF UNKNOWN	NULL SW POSITION	WHEN METER UNDICATES FULL SCALE:
10MΩ TO 100MΩ	1	MULTIPLY READOUT BY 10 AND SUBTRACT 10
90MΩ TO 1090MΩ	0.1	MULTIPLY READOUT BY 100 AND SUBTRACT 10
1,000MΩ TO 11,000MΩ	0.001	MULTIPLY READOUT BY 1,000.

Figure 5-9. Measuring resistance with Model 887A

b. With the RANGE switch set at 10, the following formula may be used to determine unknown resistance values.

$$R_x = R_i \frac{(E - 1)}{E_m} \quad \text{megohms}$$

Where:

R_X is the unknown resistance in megohms.

E is the voltage indicated on the readout dials

E_m is the voltage indicated on the meter.

R_i is the input resistance of the TVM circuit in megohms. It is 10 for the 1 and 0.1 positions of the NULL switch and 1 for the 0.01 positions when the RANGE switch is set at 10.

10. Ground loops may result when the Model 887A, in which the chassis and case are grounded, is connected to an instrument or signal-source ground at a different potential. Current may flow in this completed circuit causing erroneous meter readings. To avoid this condition the Model 887A should be connected to the power source through a 3-pin to 2-pin isolation plug. This disconnects the instrument from the external ground and effectively breaks the ground loop circuit.

11. Common mode voltages may result when the circuit element to which the instrument is connected is grounded through a second element. The situation is illustrated in the simplified diagram of Figure 5-10. In this example, if the COMMON and GROUND terminals are connected to an ac source, R2 is shunted, increasing the current through R1 and causing an erroneous measurement. During dc measurements, error is determined by the leakage resistance from the COMMON terminal to ground. The dc common-mode rejection ratio while measuring voltages up to 1000V at a relative humidity of 70% or less, is 5,000,000 to one or 0.2 uv from COMMON terminal to the GROUND terminal. When making common-mode measurements, this capacitor may become charged. This could lead to errors in succeeding low voltage measurements (under 5 volts). Connect the shorting link from the COMMON terminal to the GROUND terminal for a few seconds to discharge C1. When measuring ac common-mode voltages, a 3-prong to 2-prong line-cord isolation plug must be used. An ac load might otherwise be placed on the voltage source by capacitor C1.

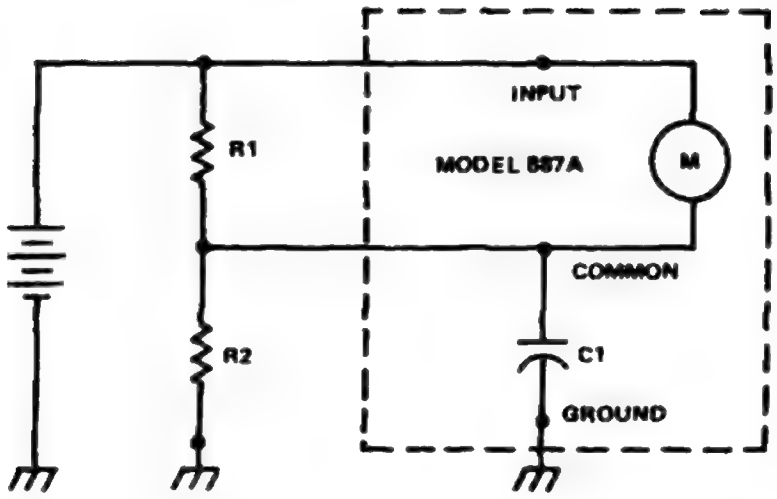


Figure 5-10. Simplified voltmeter input circuit

12. The AC to DC Converter output voltage is 1.11 times the average value of the ac input signal. Therefore, if the input is not a true sinusoid the output will probably be in error. The magnitude of the error will be in proportion to the magnitude of the distortion and its phase and harmonic relation to the fundamental. Figure 5-11 indicates error magnitude as a function of harmonic distortion.

ORDER OF HARMONIC	% DISTORTION	% ERROR FROM TRUE RMS	
		MAX. POSITIVE	MAX. NEGATIVE
ANY EVEN HARMONIC	0.1 0.5 1.0 2.0	0.000 0.000 0.000 0.000	0.000 0.0001 0.005 0.020
THIRD HARMONIC	0.1 0.5 1.0 2.0	0.033 0.167 0.328 0.667	0.033 0.168 0.338 0.687
FIFTH HARMONIC	0.1 0.5 1.0 2.0	0.020 0.099 0.196 0.038	0.020 0.101 0.205 0.420
ERRORS DEPEND UPON PHASE RELATIONSHIP BETWEEN FUND AND HARMONIC. ERROR MAY BE ANY VALUE BETWEEN MAX. POSITIVE AND MAX. NEGATIVE.			

Figure 5-11. Measurement errors as a function of input-signal harmonic distortion

13. The triple-section, low-pass filter at the input to the Null Detector attenuates ac signal components. At frequencies below 100 KHz the filter becomes less effective. When the frequency is close to a multiple or sub-multiple of the 84 Hz chopper frequency, the meter needle will oscillate at the difference frequency. If error-causing ac components are encountered, additional filtering will be required. For single frequency signals, a twin-T filter is effective and has the advantage of low total series resistance. For variable frequency signals, an ordinary low pass filter may be used.

14. Most ac sources are not stable enough to be measured in the most sensitive null range. For example, if 1.0 volt is measured with the RANGE switch set at 1 and the NULL switch set to 0.0001, the null detector sensitivity is 100 μV full scale. Since 100 μV is 0.01% of 1 volt, an ac source with a stability less than ±0.01% will cause meter fluctuations. In addition, when using the most sensitive null range, converter noise may cause meter deflection if the input signal is below 1 mV.

Learning Event 4:
DESCRIBE THEORY OF OPERATION OF THE 887AB/AN DIFFERENTIAL VOLTMETER

1. The basic operating principle of a differential voltmeter is the comparison of an unknown voltage to a calibrated reference voltage. The principle is

illustrated in Figure 5-12. Here the reference voltage is represented as a battery. A calibrated voltage divider, R1, provides an adjustable output. The unknown input voltage is connected to input terminals A and B. When the voltage divider is adjusted so that the two voltages are equal, there will be no current flow in the meter. This condition is termed a null. The magnitude of the unknown voltage is equal to the product of the reference voltage and voltage-divider ratio. In a practical differential voltmeter, the voltage-divider controls are calibrated in terms of the input voltage. Typical accuracies of this type of dc voltage measurement are of the order of 0.005%.

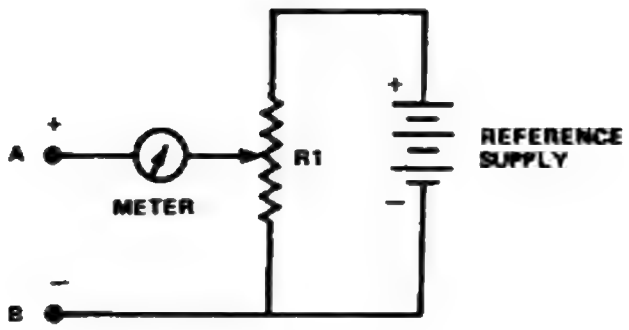


Figure 5-12. Simplified differential voltmeter

2. The principal elements of the Model 887A Voltmeter are depicted in the Functional Block Diagram of Figure 5-13. In this diagram, the Reference Supply battery of Figure 5-12 has been replaced by the Reference Power Supply; the voltage divider has been replaced by the Kelvin-Varley Divider; and the Meter has been replaced by the Null Detector. Additionally, the input circuit has been modified to include an AC to DC Converter and a DC Attenuator.

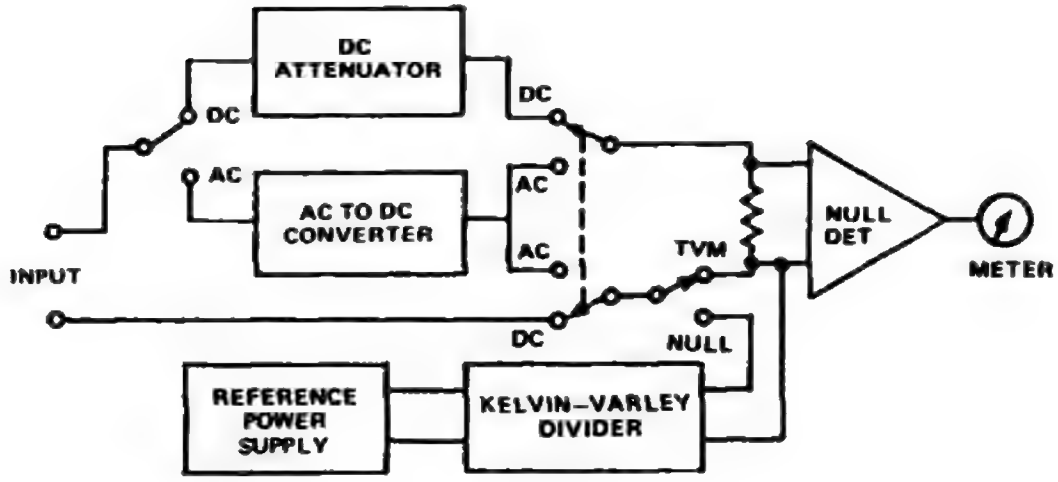


Figure 5-13. Functional block diagram, Model 887A/AB

3. The Model 887A has three basic operating modes: DC, AC, and TVM. In the dc mode, the input voltage is connected through the DC Attenuator to the NULL Detector and Kelvin-Varley Divider. The DC Attenuator attenuates input voltages above 11 volts to values within the 0- to 11-volt operating range of the Kelvin-Varley Divider. The Kelvin-Varley Divider is adjusted to make the output voltage equal to the unknown input voltage. When they are equal, the Null Detector will indicate zero on the meter. The magnitude of the unknown voltage can then be read from the frontpanel dials which are mechanically linked to the Kelvin-Varley Divider. In the ac mode, the input signal is connected to the AC to DC Converter where the ac voltage is converted to a dc voltage proportional to the average value. This dc voltage is then compared to the reference voltage as in the dc mode. In the TVM mode, the Kelvin-Varley Divider and Reference Power Supply are disconnected and the input signal is connected directly to the Null Detector. In this case the Null Detector functions as a conventional voltmeter.

4. Figure 5-14 shows the block diagram for the 887A Differential Voltmeter. As seen in this figure, the circuit is mainly composed of an ac to dc converter, a dc input attenuator, a dc transistorized voltmeter (TVM), and an extremely accurate 0- to 11-volt reference. The dc input attenuator reduces the input voltage by a factor of 100 on the 1000- and 100-volt dc range. The TVM uses a Null Detector, an attenuator, and a meter to obtain high sensitivity. The 0- to 11-volt reference uses a range divider and a Kelvin-Varley attenuator to make the output of two well-regulated zener diodes adjustable. Refer to the functional schematic for more detail. This schematic is designed to aid in the understanding of circuit theory and troubleshooting. The signal flow is from left to right and the components are laid out in a functionally logical manner.

5. The overall operation of the voltmeter may be summarized as follows: To measure the approximate value of a dc voltage between 0 and 11 volts, the unknown voltage is connected directly across the TVM attenuator. This attenuator is set in such a way that the maximum voltage for each range is reduced to a signal of 1 millivolt (100 microvolts for the 1-volt range in the highest null mode). The signal is then applied to the null detector and causes 100 microamperes to flow through the meter for full-scale deflection. To accurately measure this dc voltage, the unknown voltage is connected across the series combination of the TVM and the 0- to 11-volt reference. The reference voltage is then adjusted with the five voltage readout dials until it matches the unknown voltage as indicated by the TVM. For voltages between 11 and 1100 volts, the dc input attenuator divides the unknown voltage by 100. The 887A then operates essentially the same as for measurements from 0 to 11 volts. All ac measurements are made by first converting the ac input voltage to a dc voltage by means of the ac to dc converter. The 887A then operates essentially the same as for approximate and accurate dc measurements.

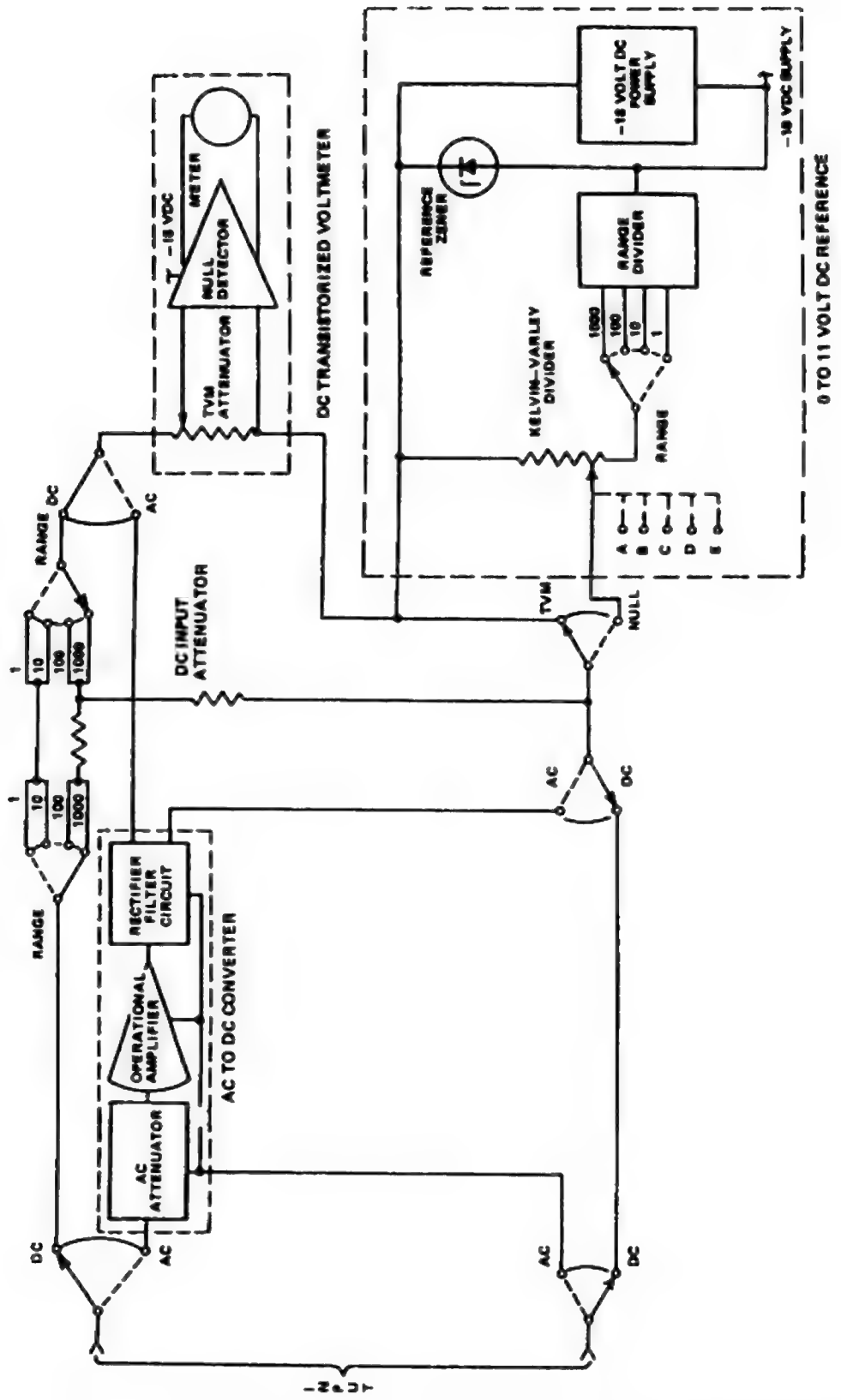


Figure 5-14. Block diagram of Differential Voltmeter Model 887A

6. In order to provide for a more complete understanding of the 887A Voltmeter, the following paragraphs describe each section of the circuit in detail.

a. Since the instrument contains a 0- to 11-volt reference, the unknown voltage is measured by comparing it to a known voltage with the aid of a NULL detector only on the 1- and 10-volt range. On the 100- and 1000-volt range, the dc input attenuator (R100 through R104)(fig 5-15 (fo)) divides the unknown voltage by 100 and this attenuated voltage is then measured by the potentiometric principle. Thus, after attenuation by 100, the 100- and 1000-volt ranges are reduced to the equivalent of 1- and 10-volt ranges. The dc input attenuator is extremely accurate and has excellent long-term stability. The 10K variable resistor (R103) is used during factory calibration to set up the proper division ratio. This adjustment can then be performed as required at regular calibration intervals.

b. The DC Transistorized Voltmeter (DC TVM) is composed of an attenuator, a null detector, and meter. The heart of the DC TVM is the null detector in which the dc signal is modulated by an electromechanical chopper, amplified by a 5-stage resistance-capacitance coupled amplifier, rectified by a transistor switch, and finally filtered to produce a DC output. The null detector has a high amount of negative current feedback. This makes the proportion of the output current feedback approximately equal to the signal voltage divided by the resistance of the feedback resistor, regardless of the amplifier characteristics. The high negative feedback also makes the amplifier relatively insensitive to the gain changes in individual transistors due to aging and replacement. The output current from the null detector is indicated on a meter that has tautband suspension. This suspension does away with all friction associated with meter pivot stickiness. Thus, any tendency for the meter pointer to stick at one point of the scale and then jump to another point is eliminated. The TVM attenuator is used to reduce the voltage span of each range to a common range usable by the null detector to produce proper meter deflection.

c. The null detector is a current feedback amplifier that drives a meter. Any feedback amplifier is essentially a null-seeking device. That is, it tends to make the voltage fed back to the input equal to the input voltage. In a current feedback amplifier, the feedback voltage is equal to the voltage drop across a fixed resistor caused by the output current or a portion of the output current. At the input to the 887A null detector, R201, C201, R202, C202, R203, and C203 form a triple-section low pass filter that reduces any ac component present on the dc voltage being measured (fig 5-15 (fo)). The difference between the voltage appearing at the output of the filter and the voltage developed across feedback resistor R236 is converted to an alternating voltage by C201, an 84 Hz chopper. The voltage across R236 is proportional to the current flowing in the meter. The alternating voltage created by G201 is amplified by a five-stage solid-state amplifier. The first stage is a p-channel field-effect transistor (Q201). The field-effect transistor provides both high impedance and low noise input characteristics. The next four stages consist of two match pair transistors (Q202 to Q205). During one portion of the chopper cycle, the output of the amplifier is clamped to approximately null detector common potential by Q206, a transistor switch. The transistor

switch is gated in synchronization with the chopper since the gating pulse comes from the voltage that is used to drive the chopper. During the other portion of the chopper cycle, the output of the amplifier is filtered by R-C filter R225-C219 to provide a dc current for the meter. A portion of the current that flows through the meter is shunted back to the 200 ohm feedback resistor R236, thus completing the feedback loop. The null detector has a basic sensitivity of 1 millivolt except in the most sensitive null mode for the 1- and 100-volt range where the sensitivity is 100 microvolts. For the two most sensitive null modes in the 100- and 1000-volt range, the sensitivity is boosted 10% to compensate for the loading effect of the TVM attenuator on the dc input attenuator. The output resistance of the dc input attenuator is 100K and the input resistance of the TVM dc attenuator is 1 megaohm. Thus, when monitoring voltage excursions, much more accurate off null readings are obtained due to the 10% boost in null sensitivity.

d. In the dc TVM mode, two positions on the TVM attenuator selected by range switch section S2H (fig 5-15 (fo)) provide the necessary reduction of the 1- and 10-volt ranges for proper null detector input. The same two positions on the TVM attenuator are used for the 100- and 1000-volt ranges because the input attenuator divides the input signal by 100 and thus reduces the 100- and 1000-volt ranges to the equivalent of the 1- and 10-volt ranges. In the differential mode, the voltage difference (unknown voltage, or unknown voltage divided by 100, minus reference voltage) is reduced as necessary by positions on the TVM attenuator selected by null switch sections S3H, S3G, and S3E to provide the basic null detector inputs of 1 millivolt or 100 microvolts.

e. In the AC TVM mode, null switch section S3H and ac-dc polarity switch section S4E (fig 5-15) provide connection to only one position on the TVM attenuator regardless of where the range switch is set. Also, in the ac differential mode, the voltage difference (converter output voltage minus reference voltage) is reduced by the same positions on the TVM attenuator as for 1 volt dc differential measurements. This is because the output of the ac-dc converter is 1 volt dc for full input on each range.

f. For the TVM, low sensitivity, and medium low sensitivity modes, the input resistance of the TVM attenuator is 10 megohms (R4 through R7). For the medium high and high sensitivity modes, the input resistance of the TVM attenuator is 1 megohm (R4 and R7). However, this is not the input resistance of the 887A for the dc TVM and dc differential mode. For the 1- and 10-volt range, the input resistance is determined by dividing the unknown voltage by the current drawn from the unknown. The current drawn from the unknown is equal to the difference between the unknown terminal voltage and the internally known voltage divided by the resistance of the TVM attenuator. The equation for input resistance can therefore be written as:

$$R_{in} = \frac{E_u}{I_u} = \frac{E_u R_a}{|E_u - E|} = \frac{E_s (R_a R_s)}{|E_s - E|} - R_s$$

where:

R_{in} = input resistance of voltmeter

$E_u = E_s - I_u R_s$ = terminal voltage of unknown

I_u = current drawn from unknown

E_s = source voltage of unknown

R_s = source resistance of unknown

R_a = input resistance to TVM attenuator

E = voltage indicated by voltage readout dials

$|.|$ = absolute value (magnitude only)

(1) Thus, the input resistance is essentially infinite (leakage resistance across the input is in the order of 10^{12} ohms) at null when E is equal to E_U and E_S. For the 100- and 1000-volt range, the dc input attenuator is always connected across the input terminals. Thus, the input resistance is equal to the resistance of the dc input attenuator which is 10 megohms.

(2) The input impedance for the AC TVM and AC differential mode depends on the input impedance of the ac to dc converter and its attenuator. The ac input impedance is thus 1 meghom and 40 picofarads.

g. The chopper drive circuit (figure 5-15 (fo)) determines the chopper timing frequency of 84 Hz. The circuit is symmetrical with the transistors biased so that they can conduct simultaneously. However, cross-coupling capacitors C105 and C106 force Q106, Q109 and Q107, and Q108 to conduct alternately. This results in a square wave varying from about 0 to 6 volts that drives chopper coil C201. The symmetry and frequency of the waveform are adjusted with R126 and R124 respectively.

h. The voltage for null detector amplifier stages, Q201 through Q205, is supplied by the same -18 volt power supply that is used to power the 0- to 11-volt reference (fig 5-15). The voltage for chopper drive circuit transistors Q106 through Q109 is obtained from a half-wave rectifier consisting of diode CR101 and an R-C filter network (R105 and C101) that supplies 6 volts dc. Current-determining resistors R238 and R240, diodes CR201, and CR202, and divider resistor R239 provide a compensating voltage for the purpose of adjusting the null detector to zero with R239 when there is no signal input. Diode CR201 keeps one side of R239 at approximately +0.6 volt dc with respect to the null detector common while diode CR202 keeps the other side at approximately -0.6 volt dc.

i. The only ac voltage component that will reduce the accuracy of the 887A is one that either saturates the null detector or one that beats with the

chopper frequency. Since the voltage required for saturation is greater than that required for beating, the null detector is most sensitive to an ac component with a frequency that is a submultiple of the chopper frequency. However, this is easy to detect because the meter will beat at the difference frequency. The low pass filter at the input of the chopper-amplifier will attenuate any ac component. The magnitude of the ac voltage appearing at the output of the filter depends on both its amplitude and frequency before filtering. For all practical purposes, one should never encounter any trouble above one hundred Hertz. Below this, the filter may not attenuate the ac component enough. However, this is not as bad as it appears. A 60-cycle ac voltage that is 1% of the input voltage will cause an error of approximately 0.001% which is well within specifications. If ac components that affect accuracy are ever encountered, additional filtering as set forth in the operating instructions will eliminate the problem.

j. Variable resistor R239 in the feedback network provides a means of adjusting the output current of the null detector to zero when there is no input signal. The gain of the null detector is adjusted by means of R230 in the feedback network for the 1-millivolt sensitivity and by means of R231 for the 100 microvolt sensitivity (fig 5-15 (fo)).

k. The recorder output is picked off divider string R226, R8, and R227 (fig 5-15 (fo)). Recorder output AMP ADJ control R8 provides a means of adjusting the output voltage up to a maximum of at least 20 millivolts at full scale deflection (disregarding 10% over-range at end of scale). The voltage at the RECORDER OUTPUT terminals is proportional to the meter reading.

l. When the 887A is used to make differential dc voltage measurements between 0 and 11 volts, an internal voltage is nulled or matched against the unknown voltage. An extremely accurate reference is therefore required. This is obtained from the 0- to 11-volt reference. The 0- to 11-volt reference is composed of a well-regulated -18-volt power supply, a range divider, and a five decade Kelvin-Varley divider. The range divider reduces the voltage from a pair of stable Zener diodes in the -18-volt reference supply to 11 volts for the 10- and 1000-volt dc ranges and to 1.1 volts for the 1- and 100-volt dc ranges before it is applied to the Kelvin-Varley divider. The Kelvin-Varley divider divides its input voltage (11 or 1.1 volts) more than 1,100,000 equal increments any number of which may be selected by setting the five decades with the five-voltage readout dials. The output of the Kelvin-Varley divider, therefore, provides an extremely accurate reference voltage.

(1) The -18-volt power supply (fig 5-15 (fo)) uses diode CR102 and filter capacitor C101 to supply unregulated dc voltage to series pass transistor Q101. In the Model 887AB, unregulated dc voltage can also be supplied by a set of batteries (BT1) in the BAT OPR and BAT CHECK modes. The -18 volts is regulated by comparing a sample of the output voltage, tapped-off divider string R109, R110, and R111, with the voltage from zener reference diodes CR 103 and CR 104 in a two-stage differential amplifier. Transistor Q103 is a dual transistor, having matched current gain and matched V_{be}, which ensures minimum voltage change due to temperature in the -18-volt reference voltage.

The output from Q103, which is proportional to the difference between the two inputs, is applied to a second state of differential amplification, Q104 and Q105. The output from Q104 is applied to the base of series pass transistor Q101. The differential amplifier adjusts the voltage drop across the series pass transistor so as to maintain a constant output voltage. The -18 volt provides operating current for the chopper drive multivibrator, and supplies a constant current through R116 and R117 to its own zener reference diodes CR103 and CR104.

(2) If the instrument is turned on with the battery voltage below about 5 volts, there is a possibility that transistor Q101 may not begin conduction. Thus, when the power switch is set to BAT CHECK, the meter would indicate an adequate battery charge, because all of the voltage drop appears across Q101. When the instrument is first turned on, the base-emitter junction of Q102 is forward biased, and Q102 conducts, which causes transistor Q101 to conduct and become saturated. As the output voltage of the -18-volt supply rises above -11 volts, transistor Q102 becomes biased off, and the differential amplifier controls the conductance of Q101.

(3) For instrument serial numbers 618-659, 691 and above, zener diodes CR104 and CR105 are enclosed in a proportionally-controlled oven, Q111, Q112, Q113, and associated components. The oven heater is R147. Transistors Q112 and Q113 are connected as a differential amplifier, with the base voltage of Q113 fixed by R153 and R154. The base voltage of Q112 is set by R150 and R155. Since R155 is temperature-sensitive, the base voltage of Q112 varies inversely with temperature. The output from the collector of Q112, which is proportional to the difference between the base voltages of Q112 and Q113, is applied to the base of Q111 and controls the conduction of Q111, which controls heater current. For example, as the oven temperature increases, the resistance of R155 decreases. This causes a more positive output from the collector of Q112, which reduces the conduction of Q111, thus reducing current through the heater R147, and decreasing heating of R147. C108 eliminates oscillations in control circuit.

(4) In the 1000- and 10-volt dc range, the Zener reference diode is connected directly to the Kelvin-Varley divider through resistors R119 and R120 by means of range switch sections S2J and S2I. The voltage drop across R119 and R120 reduces the Zener reference voltage to 11 volts at the input of the Kelvin-Varley divider. In the 100- and 1-volt dc range, range resistors (R121, R122, and R123) selected by range switch sections S2J and S2I reduce the voltage to 1.1 volts at the input to the Kelvin-Varley divider. With the ac-dc connection to the range resistors that divide the reference voltage to 1.1 volts. This 1.1 volts is then passed to the Kelvin-Varley divider by ac-dc switch section S4G. The voltage applied to the Kelvin-Varley divider is always 1.1 volts for ac because the maximum output of the ac to dc converter is always 1.1 volts.

m. The five Kelvin-Varley decades (fig 5-15), composed of resistors R301 and R366, and associated voltage dials A through E, provide a means of making the two precision voltages (11 and 1.1 volts) adjustable. The first decade has twelve 5K resistors (a 4,999.2 ohm resistor and a 2-ohm trimmer).

Two of these resistors are shunted by the 10K total resistance of the second decade. Between the two wipers of S5 (voltage dial A) then, there is a total resistance of 5K (10K paralleled by 10K).

(1) Thus, the first decade divides the voltage across it into eleven equal parts with one of the equal parts appearing across the two shunted resistors. Similarly, the second, third, and fourth decades divide the voltage across them into ten equal parts. Note that the second, third, and fourth decades each have eleven 1K resistors. The resistors may have the same value because padding resistors R328 - R329 and R315 - R316 are used across the third and fourth decades respectively to keep the proper resistance matching. The last decade, with its associated shunt resistors to keep the proper matching, is a variable resistor which can be set to pick off increments equal to less than 1/100 times the voltage across its input. The Kelvin-Varley resistors are matched for both temperature coefficient and tolerance, thus providing an overall accuracy of 0.002% absolute from 1/11 of full scale to full scale. With the null switch in any null range, the output of the Kelvin-Varley divider is connected in series with the TVM attenuator, thus providing the accurate 0- to 11-volt or 0- to 1.1-volt reference voltage required.

(2) Variable resistor R111 is used during final factory calibration to set the reference supply to -18-volts. This adjustment is not exceedingly critical and should have to be done only when a component of the reference supply has been replaced. The voltage from the Zener reference diodes is reduced to 11 volts at the input to the Kelvin-Varley divider by adjusting variable resistor R120 during calibration. Range-divider variable resistor R122 may then be adjusted for 1.1 volts at the input to the Kelvin-Varley divider. The 2 ohm trimmer resistors (odd resistors from R301 to R325) and variable padding resistors R338, R351, and R364 should require adjustment only after a component of the Kelvin-Varley divider has been replaced.

n. The ac to dc converter (fig 5-15 (fo)) is composed of an attenuator, an operational amplifier, and a rectifier-filter circuit. A pair of diodes in the rectifier-filter circuit are used to convert the unknown ac into pulsating dc. This pulsating dc is then filtered to obtain a dc voltage that is proportional to the average value of the ac input voltage. The output, however, is calibrated to indicate the RMS value of a pure sine wave. An operational amplifier with high negative feedback is used to make the rectification characteristics of the diodes linear and stable. The first stage is an n-channel field effect transistor (Q501). The field-effect transistor provides both high impedance and low noise input characteristics. The next four stages consist of two transistor doubletons (Q502, Q503, Q504, and Q506). Transistor Q505 acts as a dynamic load and thus increases the output impedance of the amplifier. The amplifier achieves a midband loop gain of approximately 70 dB with a virtually flat frequency response from 20 Hz to 20 kHz. At the output of the amplifier, full-wave rectification is used to return negative feedback to the gate of the field-effect transistor. The high negative feedback makes the amplifier practically noise free and relatively insensitive to gain changes in individual stages due to aging and transistor replacement. An attenuator is used to reduce the ac input voltage on the higher ranges to within the operating level of the converter amplifier.

(1) The auxiliary power supply for the converter is composed of Q507, Q508, Q509, and the associated components. Diode CR506 and filter network R542-C523 supply unregulated dc voltage to series pass transistor Q507. In the 887AB, regulated dc voltage is supplied from a set of batteries, BT2, in the BAT CHECK and BAT OPR modes. The emitter voltage of Q509 is set by Zener diode CR506. The base input of Q509 is taken from a divider string, R538, R539, and R540, which samples the output voltage of the -18-volt supply. Any variation in the -18 volt varies the base drive of Q509, which varies the output from the collector load of Q509. Since the output of Q509 drives Q508, the collector current of Q508 continuously adjusts the conductance of Q507 to maintain the auxiliary voltage constant at the value determined by the setting of R539.

(2) All ac measurements are made by first converting the ac input voltage into a dc voltage. The converter provides a dc output of 1 volt when full range voltage is applied to the 887A in each ac range. In the 1-volt AC range, the AC-DC polarity switch and the range switch connect the input binding posts directly to the converter input. The converter gain is of such a value that the DC output voltage is equal to the RMS value of the converter input voltage for a sine wave. For the 1000-, 100-, and 10-volt ac ranges, a separate input attenuator for each range reduces the unknown ac voltage by a factor of 1000, 100, and 10 respectively. The operation of the converter is then the same as for the 1-volt range. Thus, an output of 1 volt dc is provided for full range input of a pure sine wave on any ac range.

(3) The converter gain is adjusted with R503 in the feedback loop of the operational amplifier. Capacitor C502 in the feedback loop is used to adjust the high frequency response of the converter. The attenuation of the 1000-, 100-, and 10-volt attenuators are adjusted with R410, R406, and R403 respectively. Capacitors C405, C403, and C401 are used to adjust the high frequency response attenuators. The bias of field-effect transistor Q501 should require adjustment with R508 only when Q501 or a component in its drain-source is replaced. The amplifier output level at the collector of Q506 should require adjustment with R522 only if Q505, Q506, or a component in one of these stages is replaced.

o. The AC-DC polarity (fig 5-15 (fo)) switch is provided for selecting either the ac or dc mode of operation. When the AC-DC polarity switch is set to ac, the ac to dc converter is switched into the circuit by sections S4A, S4B, S4c, and S4d. Also, sections S4H and S4G are used to switch 1.1 volts dc to the Kelvin-Varley divider. Section S4E is used to provide proper attenuation in the TVM attenuator.

p. For the dc mode of operation, the AC-DC polarity switch may be set to the positive or the negative dc position. The polarity switch reverses the transistorized voltmeter-reference voltage combination with respect to the input. Note that a 0.01 uf capacitor (C1) is connected from the COMMON post to the chassis ground post to reduce the effect of ac circulating currents. If the instrument did not contain a polarity switch, the grounded side of any unknown voltage that is negative with respect to ground would have to be connected to the INPUT post. This would ground the INPUT post and effectively place C1 across the input. With this capacitance connected across the circuit

being measured, several problems would arise. The polarity switch provides equal convenience in measuring positive and negative voltages without the occurrence of these problems.

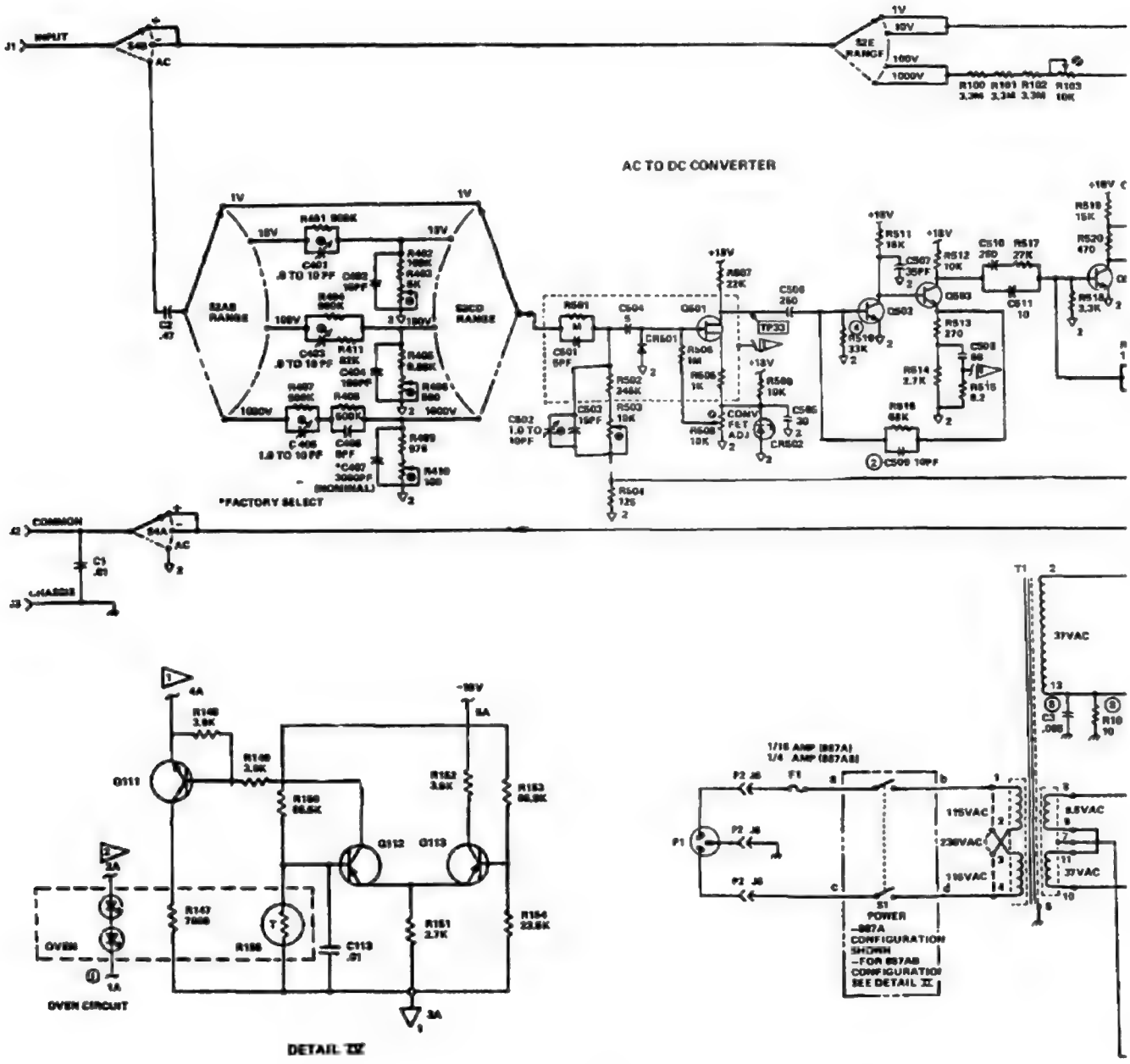


Figure 5-15 (fo). Schematic, Model 887A

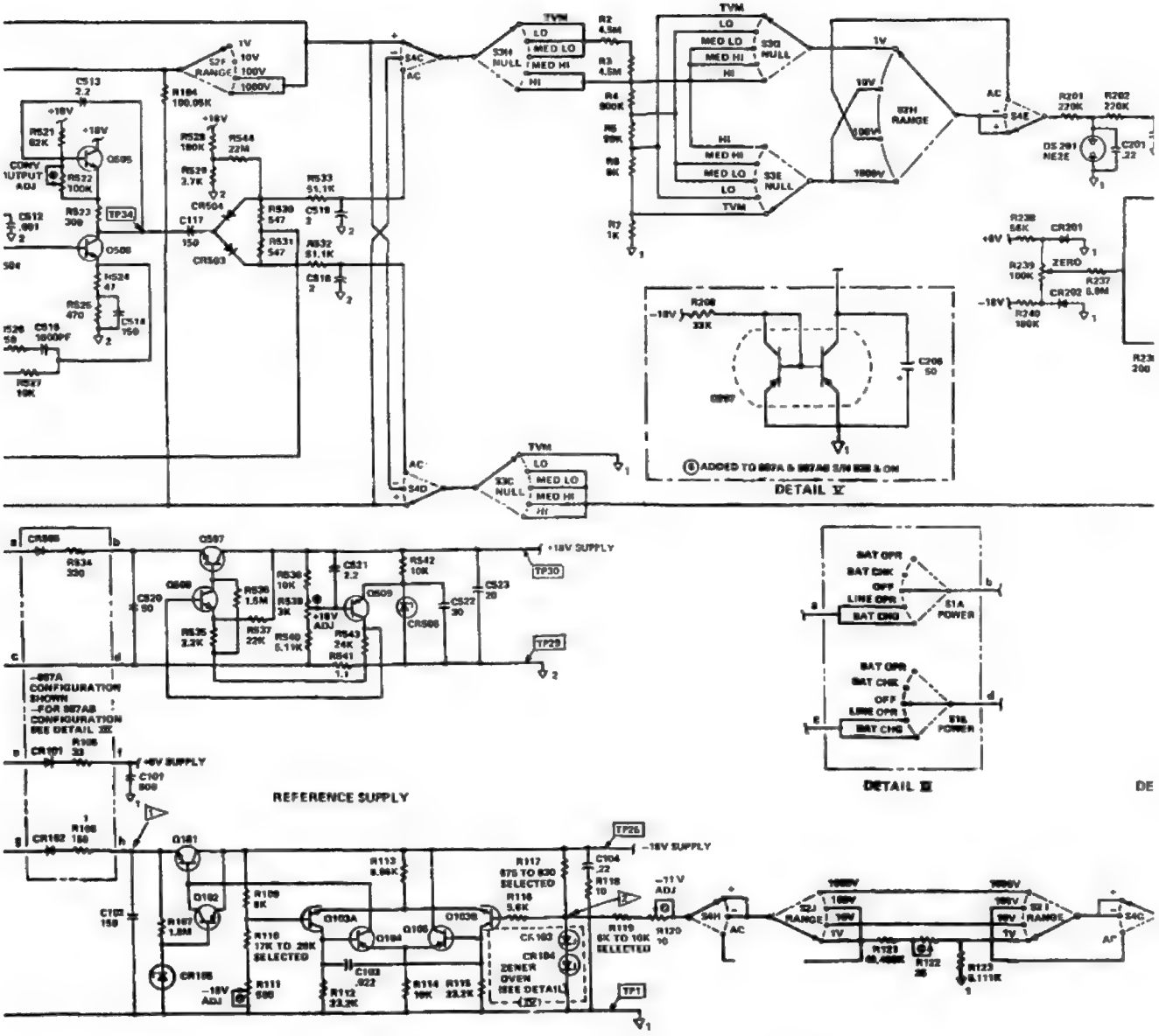


Figure 5-15a (fo). Schematic, Model 887A

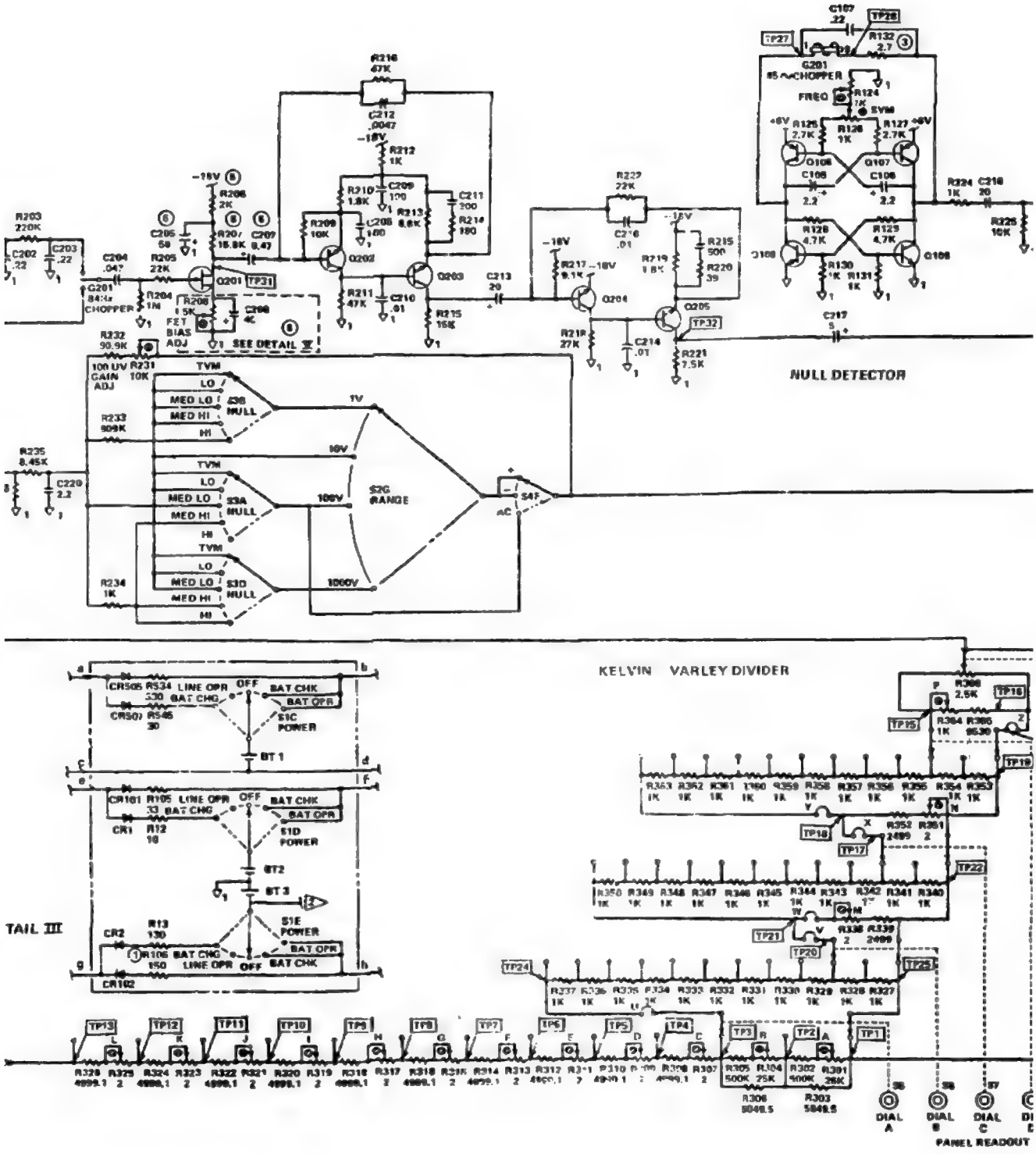


Figure 5-15b (fo). Schematic, Model 887A

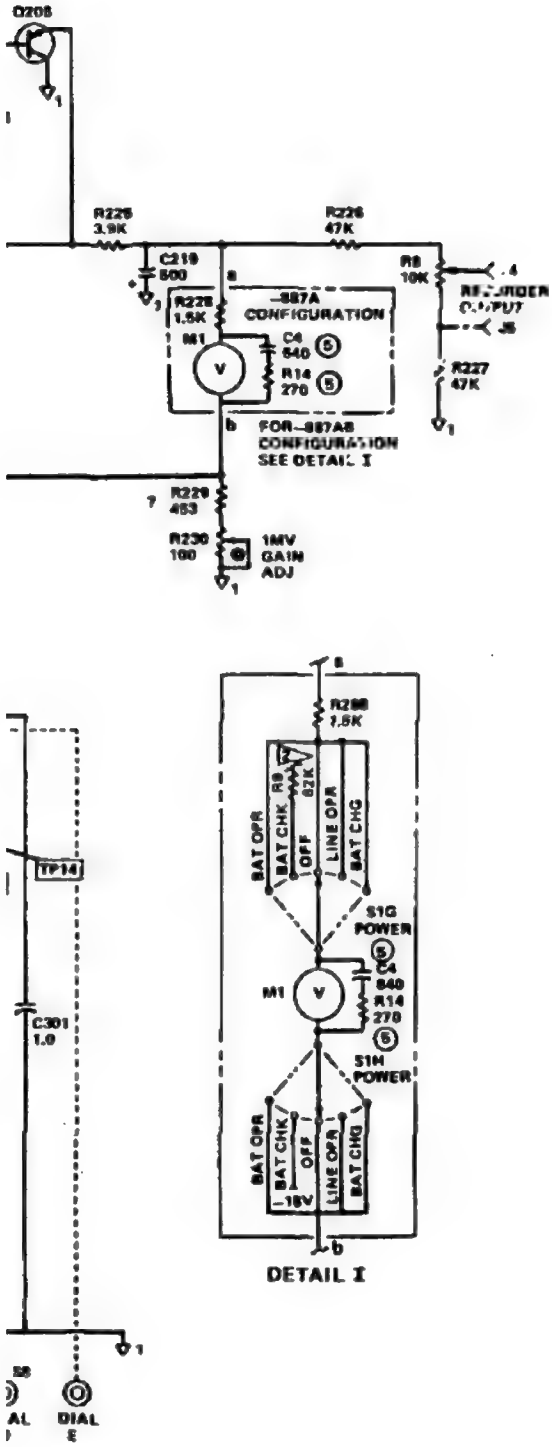


Figure 5-15c (fo). Schematic, Model 877A

Lesson 5
PRACTICE EXERCISE

1. What are the uses of the differential voltmeter?

   a. Voltmeter, potentiometer and milliohmmeter
   b. Voltmeter, potentiometer amplifier, and megohmmeter
   c. Voltmeter, potentiometer and megohmmeter
   d. Voltmeter, amplifier, and megohmmeter

2. What value of resistance can be measured with the 887AB/AN Differential Voltmeter?

   a. 1 to 10 megohm
   b. 1 to 10000 megohm
   c. 10 to 11000 megohm
   d. 10 to 1000 megohm

3. What is the accuracy of the 887AB/AN when used as a conventional voltmeter?

   a. ± .005%
   b. ± .03%
   c. ± 3.0%
   d. ± .0001%

4. What switch positions should the 887AB/AN be in when electrically zeroed?

   a. RANGE to 1, NULL to 1, readout dials zero
   b. RANGE to 1, NULL to 0001, readout dials zero
   c. RANGE to 1000, NULL to .0001, readout dials 0
   d. RANGE to 1, NULL to .0001, readout dials to 1.000000

5. If the RANGE switch is set to 10, the NULL switch is set to 0.1, and the readout dials indicate 8.50376 on the 887AB/AN, what is the value of the unknown resistance?

   a. 850.376 megohm
   b. 75.0376 megohm
   c. 840.376 megohm
   d. 8,503.76 megohm

6. What value and type of signal drives chopper coil G201 in the 887AB/AN Differential Voltmeter?

   a. 0- to 6-volt square wave
   b. 0- to 11-volt square wave
   c. 0- to 6-volt sinewave
   d. 0- to 11-volt sinewave

7. What is the value of the voltage that drives the null detector amplifier stage in the 887AB/AN Differential Voltmeter?

   a. +18 volts
   b. +6 volts
   c. -18 volts
   d. -6 volts

8. What is value of the precision voltages that are adjusted by the Kelvin-Varley divider in the 887AB/AN Differential Voltmeter?

   a. 11 and .6 volts
   b. 11 and 1.1 volts
   c. -18 and 11 volts
   d. -18 and +6 volts

ANSWERS TO PRACTICE EXERCISES

Lesson 1

1.	d	LE 1	para 2	pg 1
2.	c	LE 1	para 3	pg 1
3.	b	LE 2	para 1	pg 2
4.	a	LE 2	para 3	pg 3
5.	c	LE 3	para 1	pg 3
6.	b	LE 3	para 2	pg 4
7.	a	LE 3	para 3	pg 4
8.	c	LE 4	para 1	pg 5
9.	d	LE 4	para 1	pg 5
10.	a	LE 4	para 2	pg 6
11.	b	LE 5	para 4b	pg 8
12.	a	LE 5	para 3	pg 7
13.	a	LE 6	para 3b	pg 8
14.	b	LE 6	para 4	pg 9
15.	c	LE 6	para 4	pg 9

Lesson 2

1.	b	LE 1	para 1	pg 13
2.	d	LE 1	para 4a(5)	pg 17
3.	a	LE 1	para 5b(1)	pg 22
4.	b	LE 2	para 1	pg 25
5.	c	LE 2	para 2	pg 25
6.	d	LE 2	para 4	pg 26
7.	b	LE 3	para 3a(5)	pg 34
8.	a	LE 3	para 3b(1)	pg 34
9.	b	LE 3	para 4a	pg 36
10.	d	LE 3	para 5b	pg 37
11.	b	LE 4	para 2	pg 37-38
12.	a	LE 4	para 4b	pg 39
13.	c	LE 4	para 4b	pg 40
14.	b	LE 5	para 2	pg 40-41
15.	a	LE 5	para 4c	pg 44
16.	c	LE 5	para 5a	pg 45

Lesson 3

1.	d	LE 1	para 2	pg 52
2.	c	LE 1	para 5	pg 53
3.	a	LE 1	para 12	pg 55
4.	a	LE 2	para 3	pg 56
5.	b	LE 2	para 4	pg 56-57
6.	c	LE 3	para 2b	pg 55
7.	c	LE 3	para 2e	pg 57
8.	a	LE 3	para 4b	pg 59
9.	b	LE 3	para 4b	pg 59
10.	b	LE 4	para 5	pg 64

Lesson 4

1.	a	LE 1	para 3c	pg 70
2.	b	LE 1	para 3b	pg 69
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